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VHV
Poole

THE
CALORIFIC POWER OF FUELS

WITH A COLLECTION OF AUXILIARY TABLES AND TABLES SHOWING THE HEAT OF COMBUSTION OF FUELS, SOLID, LIQUID AND GASEOUS

BY

HERMAN POOLE, F.C.S.

THIRD EDITION, REWRITTEN

By ROBERT THURSTON KENT, M.E.

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TO

My Wife

THIS BOOK IS AFFECTIONATELY

DEDICATED

PREFACE TO THE THIRD EDITION

WHEN the writer was requested by the publishers to undertake a revision of the late Mr. Poole's work, a study of fuels revealed that since the second edition of this book was published in 1900 there have been many advances in the subject. Not only have new fuels come into use, but the methods of investigation of the earlier scientists have been improved and more accurate data are now available than when the book was first prepared. In fact, the work of some of the investigators on which the first edition was based is now generally discredited.

In view of these facts it was deemed advisable to practically rewrite the book and to incorporate in it the latest researches, not only in coal, but on the fuels which have to a great extent replaced or supplemented coal. Among these are the fuel oils, gasoline, denatured alcohol and natural, producer, blast furnace and coke oven gas.

While the knowledge of the coals of the United States at the time of the first edition of this book represented the work of a large number of independent investigators, there was no coherency in their researches. In recent years, however, a systematic study of coal and many other fuels has been made by the United States Geological Survey and the United States Bureau of Mines. These studies, which are far in advance of anything of similar character yet attempted, form the basis of this third edition. The original tables of the author have been preserved almost intact, however, except where proved inaccuracies were discovered. The researches of the Geological Survey and the Bureau of Mines form an addition to the original data.

While the earlier editions were based on the metric units, the present edition is based largely on the English system of units. Where the metric units are retained, the matter represents the

work of Mr. Poole. The reviser believes that the use of the pound and the British thermal unit instead of the kilogram and the calorie will make the book more serviceable to the user of fuel in the United States. It is believed that the book in its present form and arrangement will serve a useful purpose in every industry which uses fuel.

ROBERT THURSTON KENT.

NEW YORK, Nov. 16, 1917.

PREFACE TO THE FIRST EDITION

THE books on fuels hitherto published in English contain only a few scattered facts regarding their calorific powers, how they are obtained, and the practical use made of them. Quite frequently these books are consulted for these facts, and the information they do contain is utilized to its fullest extent. It was thought that a book especially devoted to this subject containing all the reliable data might be of interest, and in furtherance of that idea this book is published.

The work commenced as a translation of M. Scheurer-Kestner's "*Pouvoir Calorifique des Combustibles*"; but changes became necessary to adapt it to American methods and data, and it was deemed advisable to simply use the skeleton of the work and fill it in, as considered best. Even this skeleton has hardly been preserved intact, as the arrangement of much of the material has been changed, many portions omitted, many new ones supplied, and in some of the original discussions the argument has been so changed as to point nearly opposite to that advocated by M. Scheurer-Kestner.

The work embraces only that portion of calorimetric determinations having a bearing on fuel values. A concise description is given of the leading calorimeters, those most commonly used being described more fully than the others, and some examples of working and calculations are added.

Coal being the principal fuel naturally receives more space than any of the others, and most of the examples and calculations are based on results from this fuel. The other fuels are discussed, briefly, some space being given to the heats of formation of the different kinds of gas, and the advantages gained by their use. A short account of theoretical flame temperatures is given, with the methods of calculating and applying the same.

A set of tables of constants used in this and allied subjects is given, and finally a collection of calorimetric and analytic data on all the kinds of fuel used. It is believed that these tables are fuller and more complete than any previously published in any language, and in collating them all available books and periodicals have been freely used. In all instances where the author was known, he has been credited with his results. Of course in such a large number some unreliable data may have crept in, but all possible pains have been taken to exclude any such.

For help in the work, and especially the tabular matter, the author is under obligations to many. Prominent among them are Profs. R. C. Carpenter, E. E. Slosson, W. O. Atwater, and D. S. Jacobus; and Messrs. William Kent, R. S. Hale, F. L. Slocum, W. B. Day, and C. E. Emery. The Astor Library and the Libraries of the American Society of Civil Engineers and the American Sociery of Mechanical Engineers were freely used, and much help obtained from the librarians. Most of the cuts are from Scheurer-Kestner's book; a few were taken from Lunge and Hurter's Alkali-Maker's Handbook; some from Groves and Thorpe's work on Fuels; a few from the Reports of the American Society of Mechanical Engineers; two from Dingler's *Polytechnic Journal;* one from the *Scientific American Supplement;* and one from *Engineering News.*

The author knows well that the book is far from perfect or complete, but it is as near so as could be made with the diverse kinds of material obtainable. Some errors, especially in the tables, may be found, which he hopes to correct in the future.

That it may be found of service and aid to others in their work on fuels is the sincere wish of the author.

HERMAN POOLE.

NEW YORK, Jan. 1, 1898.

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CALORIFIC POWER OF FUELS

CHAPTER I

INTRODUCTORY

FUELS

FUELS are those substances containing carbon, or carbon and hydrogen, which are utilized for the heat they produce upon union with oxygen. The products of this union, called combustion, are carbon dioxide or carbon dioxide and water. Many fuels, such as wood, peat, crude petroleum, etc., exist naturally; others, such as coke, charcoal, coal gas, etc., are formed artificially.

The fuel *par excellence* to-day is coal. Improvements in transportation allow deliveries at points more and more remote from the mines, and the increasing demand, aided by new and improved machinery, tends to lower the cost. New locations are still being discovered, and the old ones are being worked more thoroughly and completely. A large portion of this book will be devoted to coal, other fuels being treated incidentally; and such treatment is fitting, since it is the study of coal to which the energies of physicists and engineers are still principally devoted in their researches on the calorific power of fuel.

For convenience of discussion the fuels will be divided into three general heads:

Solid fuels—coal, lignite, peat, coke, charcoal, and wood.

Liquid fuels—petroleum, shale oils, vegetable and animal oils.

Gaseous fuels—coal gas, producer gas, water gas, blast furnace gas, coke oven gas, mixed gas, natural gas.

CALORIFIC POWER OR HEAT VALUE

The quantity of heat generated by the combustion of a definite quantity of fuel in oxygen is called the calorific power, heat value, or heat of combustion. It is measured in calories or British thermal units (B.T.U.).

The *Calorie* is the quantity of heat required to raise the temperature of 1 kilogram of pure water 1 deg. Cent. It is frequently stated to be the quantity of heat required to raise 1 kilogram of water from 15 to 16 deg. Cent.

The *British thermal unit* is the quantity of heat required to raise the temperature of 1 lb. of pure water 1 deg. Fahr. Peabody gives it as the heat required to raise the temperature of 1 lb. of water from 62 to 63 deg. Fahr., while Marks and Davis give it as $^1/_{180}$ of the heat required to raise the water from 32 to 212 deg. Fahr., and this is the definition that is now (1917) generally accepted.

1 calorie = 3.968 B.T.U.; 1 B.T.U. = 0.252 calorie.

Other units of heat are: (1) The *pound-calorie*, the heat required to raise the temperature of 1 lb. of water 1 deg. Cent.; (2) the *gram-calorie*, or the heat required to raise 1 gram of water 1 deg. Cent.; (3) the *mean calorie*, which is $^1/_{100}$ of the heat given up by 1 gram of water in cooling from 100 deg. to 1 deg. Cent. A calorie, when used as the measure of the heating value of a fuel is the number of units of weight of water whose temperature may be raised 1 deg. Cent. by the combustion of one unit of weight of the fuel, the unit of weight being 1 gram, 1 kilogram or 1 lb. A calorie, thus used, is equivalent to 1.8 B.T.U.

HEAT OF COMBUSTION

The combustible constituents of fuel, such as carbon, hydrogen, sulphur, carbon monoxide, methane, or marsh-gas, etc., when burned in oxygen or air generate a certain definite amount of heat per pound of combustible. The heating value of carbon is 14,544 B.T.U. according to Favre and Silbermann and 14,647 B.T.U. according to Berthelot. Hydrogen has a heating value of 62,032 B.T.U. according to Favre and Silbermann and 61,816 B.T.U.

according to Thomsen. For ordinary practice the figures 14,600 B.T.U. are used for carbon burned to carbon dioxide and 62,000 B.T.U. for hydrogen burned to steam—the steam being condensed to liquid water. The heating value of any fuel such as coal which consists of a mixture of combustible and non-combustible substances may be determined directly by means of a calorimeter, or it may be calculated from the chemical analysis of the fuel by Dulong's formula which is:

$$\text{Heating value} = \tfrac{1}{100} \times \left[14{,}600\text{C} + 62{,}000\left(\text{H} - \frac{\text{O}}{8}\right) + 4000\text{S} \right].$$

Expressed in terms of centigrade units this formula will read:

$$\text{Heating value} = \tfrac{1}{100} \left[8140\text{C} + 34{,}400\left(\text{H} - \frac{\text{O}}{8}\right) + 2250\text{S} \right].$$

In these formulæ C, H, O and S are respectively the percentages of carbon, hydrogen, oxygen and sulphur contained in the fuel. The term $\left(\text{H} - \frac{\text{O}}{8}\right)$ is called the available or disposable hydrogen, or that which is not combined with the oxygen in the fuel.

If instead of burning to carbon dioxide, carbon is burned to carbon monoxide it will generate but 4451 B.T.U. according to Favre and Silbermann. If this carbon monoxide is later burned to carbon dioxide an additional 10,093 B.T.U. will be generated, making the total heat of combustion of the two processes the same as if the carbon was burned to carbon dioxide in the first place. Dulong's formula, noted above, does not hold true in the case of a mixed gaseous fuel containing carbon monoxide, nor does it appear to hold true with some hydrocarbon gaseous fuels such as methane; while it does appear to hold for ethylene and benzol.

The table on page 4, from Steam Boiler Economy by William Kent, second edition, shows the heat of combustion of various substances in oxygen.

The heating value of methane, CH_4, if calculated according to its composition by the formula 8080C+34,462H, using Favre and Silbermann's figures, is 14,675 Centigrade heat-units, instead of 13,063, the value determined by a calorimeter, a difference of 1612 heat-units. The calculated heating value of ethylene,

C_2H_4, is 11,849, and that of benzole gas, C_4H_4, is 10,109 heat-units, differing respectively from the calorimetric values only 9 and 7 heat-units.

HEAT OF COMBUSTION OF VARIOUS SUBSTANCES IN OXYGEN

	Heat-units.		Authority.
	Cent.	Fahr.	
Hydrogen to liquid water	34,462	62,032	Favre and Silbermann
	34,342	61,816	Thomsen
Carbon (wood charcoal) to carbon dioxide, CO_2	8,080	14,544	Favre and Silbermann
	8,137	14,647	Berthelot
Carbon, diamond to CO_2	7,859	14,146	Berthelot
Carbon black diamond to CO_2	7,861	14,150	Berthelot
Carbon, graphite to CO_2	7,901	14,222	Berthelot
Carbon to carbon monoxide, CO	2,473	4,451	Favre and Silbermann
CO to CO_2, per unit of CO	2,403	4,325	Favre and Silbermann
	2,385	4,293	Thomsen
CO to CO_2 per unit of C $= 2\frac{1}{3} \times 2403$	5,607	10,093	Favre and Silbermann
Methane (marsh-gas), CH_4 to CO_2 and H_2O	13,120	23,616	Thomsen
	13,063	23,513	Favre and Silbermann
Ethylene (olefiant gas), C_2H_4 to CO_2 and H_2O	11,858	21,344	Favre and Silbermann
	11,957	21,523	Thomsen
Benzole gas, C_6H_6 to CO_2 and H_2O	10,102	18,184	Thomsen
	9,915	17,847	Favre and Silbermann
Acetylene, C_2H_2 to CO_2 and H_2O	10,109	18,196	Calculated
Sulphur to SO_2	2,250	4,050	N. W. Lord

Other authors and experimenters have tried to interpret their results by a general formula with varying success. Many of them by working on a certain number of coals from a certain location work out a formula which applies to that set of coals, but not as well to another set.

Mahler formulated one based on the results of calorimetric determination of the heat of combustion of 44 different kinds of fuel. It is

$$\text{Heating value (calories)} = \frac{8140\,C + 34{,}500\,H - 3000(O+N)}{100};$$

or simplified,

$$\text{Heating value} = 111.4\,C + 375\,H - 3000;$$

or,

$$\text{Heating value (B.T.U.)} = 200.5\,C + 675\,H - 5400.$$

With the coals he examined he found a very close agreement between the results calculated by this formula and those observed. A similar but not equally close concordance was

found using the Dulong formula. With wood and lignites the difference amounted to 2 per cent. His formula applies also to other substances whose constituents are accurately known. Cellulose, the heat of combustion of which according to Berthelot is 4200 calories, by Mahler's formula is 4264.

In summing up he says: "From a scientific point of view, in the present state of our knowledge on the subject, we cannot give a general formula depending strictly on the chemical composition which will give the calorific power of combustibles, substances so complex and varied."

The Power Test Committee of the American Society of Mechanical Engineers in the 1915 Boiler code recommends the formula

$$14{,}600\,C+62{,}000\left(H-\frac{O}{8}\right)+4000\,S,$$

in which C, H, O, and S refer to the proportions of carbon, hydrogen, oxygen, and sulphur, respectively.

Lord and Haas in a paper read before the American Institure of Mining Engineers, Feb., 1897, state that in a series of forty Pennsylvania and Ohio coals they found differences varying from $+2.0$ to -1.8 per cent between the calculated and the observed results, and an average difference of -0.12 per cent.

In 1896 Bunte published some analyses and calorimetric tests of gas-cokes, showing a difference of from $+0.04$ to -1.2 per cent.

Three elements enter into these cases, the analysis, the calculation, and the combustion; all may be erroneous. As the matter stands now the weight of error seems to be on the side of the analysis, as our methods of analysis, especially in water determinations, are not entirely satisfactory; yet it must be confessed that some of the most recent analyses give a basis from which very close agreement can be calculated. With such fuels as coke, charcoal, or anthracite, having but little volatile matter, the results agree quite well, but with the bituminous coals, asphalts, mineral oils, etc., which are so very complex, the differences are greater.* In these the actual proximate

* Mahler's limit for Dulong's formula is $O+N>15$.

chemical constitution seems to make a difference. It may be safely stated, however, that for ordinary industrial uses, in absence of the possibility of a calorimetric test, and with coals having under 20 per cent of volatile matter, a fairly accurate approximation may be arrived at by calculation.

If possible, by all means have a calorimetric test. If not possible, use the best analysis available.

Calculation from Quantity of Oxygen Used.—This is the litharge reduction test in which the combustible is mixed with an excess of litharge and heated in a crucible. The button of lead formed shows the amount of oxygen consumed, from which the heating value is determined by Welter's formula. This formula is based on the hypothesis that the heat of combustion is proportional to the quantity of oxygen consumed and is

$$\text{Heating value} = mP,$$

in which m is the coefficient previously determined, and P is the weight of oxygen necessary for the combustion of 1 kilogram of the substance.

Giving P the value resulting from the use of the equivalents—16 for oxygen to burn 6 of carbon, and 8 for oxygen to burn 1 of hydrogen—we have

$$P = \tfrac{16}{6}\mathrm{C} + 8\mathrm{H} = 8\left(\frac{\mathrm{C}}{3} + \mathrm{H}\right);$$

and the general formula becomes

$$\text{Heating value (calories)} = 8m\left(\frac{\mathrm{C}}{3} + \mathrm{H}\right) = 26{,}880\left(\frac{\mathrm{C}}{3} + \mathrm{H}\right).*$$

In using this method the heat should be increased very slowly. Mitchell substituted white lead for litharge and claimed to obtain uniform results.

This formula was recommended by Berthier, and has been used since by a few others. It is faulty, as was shown by some of Berthier's own determinations in which contradictory results were obtained. Dr. Ure showed that no uniform results could be obtained using the same materials. Scheurer-Kestner in 1892

* Value given by M. Ser.

showed that the formula not only gave erroneous results, but actually reversed the relation of combustibles. In one case cited the heats actually obtained by a calorimeter were 8813 and 8750, while by the litharge test they were 7547 and 7977. The results were not only low, but reversed the ratio.

This method is allowable only in cases where the crudest approximations are desired and where no analyses or calorimetric tests can possibly be made.

CHAPTER II

CALORIMETRY

THE heat of combustion of a fuel can be determined, as well as by calculation, by an instrument known as the calorimeter. The earliest calorimeter consisted of a block of clear ice in which a cavity was made—the cavity being closed by another slab of ice. The body whose power of heat emission was to be measured was heated to a known temperature, usually 100 deg. Cent. and introduced into the cavity in the ice which was then quickly closed with the covering slab. The amount of water melted from the ice during the period in which the body was cooling to the temperature of the ice was removed from the cavity and weighed. The quantity of water so formed was the measure of the heat emissive properties of the body.

Modern calorimeters as used to determine the heat of combustion of fuels, consist essentially of a combustion chamber in which the fuel is burned in oxygen, a vessel containing a known weight of water in which the combustion chamber is immersed and thermometers for measuring the rise in temperature of the water after combustion has taken place. The several types of calorimeters which have been used vary in the number and style of auxiliary appliances and details, but their essential features consist of the three parts noted above. The combustion chambers are either under a constant pressure as in the calorimeters of Rumford, Favre and Silbermann, etc., or they have a constant volume as in the calorimeter of Andrews, Berthelot, etc. In the determination of the heat of combustion of solids the difference of results is so small as to be negligible. With gases, however, the case is different and the conditions under which the result given was obtained should in all cases where possible be stated.

The first calorimetric experiments date from Lavoisier and Laplace. In 1814 Count Rumford replaced the ice calorimeter of Lavoisier by an apparatus in which the heat developed during

the combustion was absorbed by water. It was some time after, 1858, that Favre and Silbermann discovered the causes of the great errors of their predecessors, and published methods for correcting some while avoiding others. We owe to them, above all, the observation that, even when supplied with pure oxygen, combustion may be only partial, on account of the formation of combustible gases.

They determined that this occurs generally, and gave a method of estimating the unburned gases, so as to make allowances in the calculation.

Carbon, which, before their time, had given only 7624 calories to Laplace, 7386 to Clement-Desormes, 7915 to Despretz, 7295 to Dulong and 7678 to Andrews, yielded to Favre and Silbermann 8081 after correction for carbon monoxide in the waste gases. This quantity has since been increased to 8140 by the latest determination of Berthelot. Berthelot and Vielle have shown that by using oxygen under pressure complete combustion can be attained.

THERMOMETERS

The thermometer is one of the most important parts of the calorimeter. The accuracy of the determinations made depends upon the accuracy of the thermometer, the exactness of the reading and the corrections which must be introduced.

Favre and Silbermann employed a thermometer of their own design, divided into 0.1 degree and graduated from 32 to 0 deg. Cent. Each degree occupied about 0.3 in. By means of a cathetometer they read to 0.01 degree. Their calorimetric bath of 2 litres capacity was subjected to at least 8 degrees elevation in temperature, and the quantity of substance necessary to use at times exceeded 2 grams. To lessen this amount of rise of temperature and also the time of combustion, they used longer thermometers, with scales reading to 0.002 degree or even to 0.001 degree. Scheurer-Kestner used a thermometer divided to 0.02 degree with his Favre and Silbermann calorimeter. Since then they have been used generally. Such thermometers are difficult to work with, and require care in manipulation, and often a series of thermometers or at least two with scales in sequence are employed. If the initial temperature of a calorimetric bath is

found a little above the highest graduation on the first thermometer, and if the rise in temperature of the bath amounts to 2 degrees, we must substitute the second one having for its lowest degree the highest of the first. Besides the trouble of substitution, it necessitates a correction for agreement of the degrees common to the two instruments. To obviate this difficulty the "metastatic" thermometer was invented by Walferdin and described in the Comptes Rendu de l'Académie des Sciences, 1840, p. 292, and 1842, p. 63.

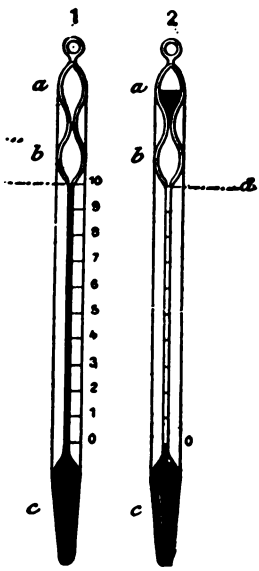

FIG. 1.—Metastatic Thermometer.

As it is not advisable to have the increase of temperature more than 3 or 4 deg., and as this increase must be measured very closely, thermometers are used in which the stem is so drawn out and divided that small fractions of a degree can be easily read. The divisions of the scale should not be greater than 0.25 deg., and much finer is desirable.

Many physicians use special thermometers having the reservoir and the tube near the zero point blown large enough to hold all the mercury needed from 0 to 16 deg. or to the beginning of the divisions. The graduations, engraved on the glass, should then begin and the tube be drawn out so that they may be sufficiently fine. Too long a tube (over 18 in.) is liable to damage. If the mercury cylinder be too large it does not respond quickly enough to minute changes in temperature. Readings of the thermometer are usually made with a cathetometer, and hence 0.02 deg. is sufficiently small. The length of a degree should be at least 1 in.

With all thermometers it is essential that the glass of the bulb should be rather thin, or the thermometer will be "too slow." The slightest difference in temperature must be shown immediately by a movement of the mercurial column. To test for sensibility read the height of the column and then place the hand on the bulb. If sufficiently sensitive the mercury will descend quickly from the

expansion of the glass and afterwards rise. In thermometers divided to 0.01 deg. this movement should be immediate, and over several hundredths of a degree.

In ordinary calorimetric experiments the correction due to the length of the mercury column flowing out of the bulb may be neglected for several reasons. The experiments should be made in a room where the temperature is nearly the same as that of the calorimetric bath. Such correction would be of very little consequence for slight changes of temperature, and the experimenter should plunge the thermometer into the bath as deep as is necessary to take the reading at the level of the eye.

INSTALLATION OF CALORIMETER

The calorimeter should be placed in a room free from sudden changes in temperature and consequently protected from direct sunlight. If it is not entirely protected from solar radiation, the apparatus may be set up on the north side and shaded from the direct midday sun by a screen.

The calorimeter cylinder with its accessories, as well as the distilled water used, should remain in the water long enough to acquire its proper temperature. The cylinder should be protected as much as possible from radiation by envelopes which vary according to circumstances; Favre and Silbermann used a cylinder with a double wall. The external one was filled with water, and between this one and the cylinder proper swan's down was packed. The upper part of the cylinder also had a layer of thick paper covered with down on the under side.

Berthelot states that the down is more troublesome than useful, and that it may be omitted with advantage. The space between the cylinder and its envelope forms a layer of air which is an excellent non-conductor. In modern instruments the down is replaced by a thick layer of felt. Berthelot even omits this covering, stating that the great cause of loss of heat was not from radiation, but due to evaporation produced by the agitation of the water in contact with the air. He surrounds his cylinder with a layer of air inside of the envelope of water, and outside of all a layer of felt 0.8 in. thick. By this means external influence is much reduced.

EVALUATION OF THE CALORIMETER IN WATER

When the fuel is burned in the combustion chamber of the calorimeter, the heat generated is absorbed by the water in the apparatus, and the apparatus itself. If all the heat were absorbed by the water, and none whatever by the apparatus, the quantity of water would have to be increased by an amount whose heat absorbing capacity would be exactly equal to that of the calorimeter. This quantity is known as the " water value " of the calorimeter. The water value includes the combustion chamber, the immersed pieces, thermometer, supports, etc.

Following is an example of the calculation of the value in water of a Favre and Silbermann calorimeter:

Copper, 1145.651 grams at 0.09516 specific heat	= 109.008 grams
Platinum, 22.810 grams at 0.0324 specific heat	= 0.706
Value in water of the chamber and accessories	= 109.714
Thermometer, weight of glass immersed, 12 grams at 0.198	= 2.400
Mercury, 63 grams at 0.332	= 2.070
Total equivalent of water	= 114.184

which added to the 2 kilograms of water in the bath makes a total of 2114.184 grams of water.

The calorimetric weight for the Berthelot bomb at the College of France in 1888 was 398.7 grams for bomb and accessories.

The water value of the calorimeter used by Lord and Haas at the Ohio State University, Columbus, O., was determined as 465 grams. Mahler's apparatus had a water equivalent of 481 grams. Still, it is better to determine this equivalent by actual experiment, as we are not sure of the specific heat of the metal of the bomb, which might, however, be determined by a sample taken from the original block of which it was made.

Several methods may be employed for this.

When we use the calorimetric bomb, we burn in the obus, using 2000 grams of water, a known quantity of a substance of fixed composition, and of which the heat of combustion is known, as sugar, or naphthalin. We then use less water and burn a smaller quantity of the substance. If 1 gram of substance was taken the first time, we may take 0.8 gram with 1800 grams of water the second time. We than have two equations, from which we eliminate the heat of combustion of the substance and deduce thence the value in water of the cylinder, etc.

This method, suggested by Berthelot, may be replaced by the following, to which he gives the preference:

Pour into the calorimeter a certain quantity of warm water, at 60 deg. Cent. for instance. This water is previously contained in a bottle, and the temperature is measured by a thermometer placed inside. As control, operate first without the bomb in the cylinder and afterwards with it in place.

One test of this kind gave Berthelot a value of 354 calories for the bomb. The value deduced by calculation from specific heat was 355.4. Below is the detailed calculation giving the separate parts of the bomb.

Names of the Different Parts.	Soft Steel.		Platinum.		Brass.	
	Weight in Grams.	Value in Water.	Weight in Grams.	Value in Water.	Weight in Grams.	Value in Water.
Crucible	1709.7	187.61	728.8	23.63	.....	.....
Cover	221.2	24.28	528.8	17.15	.....	.....
Stop-cock	11.7	1.28	.....	.....	20.0	1.86
Cone-screw and socket of fire-carrier	.....	.....	.....	.....	2.97	0.37
Movable accessories serving for suspension and kindling	.....	.....	33.0	1.07	.....	.....
Screw of bomb	802.7	88.08				
Movable foot of bomb	.....	.....	.....	.....	108.9	10.13
Totals	2745.3	301.24	1290.6	41.85	132.9	12.36

Recapitulation

Metals Used.	Weight in Grams.	Calculated Value in Water.
Steel	2745.3	301.24
Platinum	1290.6	41.85
Brass (calorimeter and agitator omitted)	132.9	12.36
Weight of bomb	4168.8	355.45
Value in water by direct test	.....	354.7

CORRECTIONS FOR THE READINGS

The corrections to be applied to thermometric readings, besides those due to the thermometer itself, are of various kinds, and naturally vary with the kind of calorimeter used. Some, however, are common to all.

The correction relative to heating and cooling concerns all calorimeters. Favre and Silbermann made this correction with

a coefficient previously determined, once for all, by a series of experiments. For example, the coefficient that they found for their calorimeter (± 0.0020225) represents the influence of the external temperature through the envelope and packings for one minute and one degree.

Instead of a coefficient of correction thus determined, a system of correction devised by Regnault and Pfaundler is preferable. This system is superior to the preceding, as it allows consideration of all external conditions at the time of the experiment. It is evident, for example, that the evaporation of a liquid may vary in such proportions that a fixed coefficient will not always represent it.

The system of Regnault and Pfaundler does not need previous experiments nor a determined coefficient. It rests on observations of the thermometer immersed in the bath a few minutes before and after the experiment, or at the times when external influence is at its minimum or maximum. Knowing the value of these two kinds of influence, it is easy to calculate it for the whole duration of the test.

It is well to continue the observations before combustion for some five minutes. These five minutes should be preceded by at least ten minutes' immersion of the combustion chamber with the agitator, so as to establish equilibrium of temperature between the cylinder and the water.

Suppose the initial correction corresponding to the first period to be zero—which is rare, it is true, but simplifies the demonstration—and that the observations have given the following data:

Initial temperature of bath	18.460°
After 1 minute	19.700
2	20.540
3	20.670
4	20.680
5	20.676
6	20.665
7	20.655
8	20.640
9	20.630
10	20.620

The combustion once commenced is continued until after the fourth minute and ends between the fourth and fifth minutes, but the equilibrium of temperature between the bath and the combustion-chamber is not established until the eighth minute, the time when the variation due to difference between them has become regular (0.010 deg. per minute).

A table of corrections is formed as follows:

	18.460°		
1st minute....	19.700	Mean 19.080°	Difference 0.620°
2d	20.540	20.120	1.660
3d	20.670	20.605	2.145
4th	20.680	20.675	2.215
5th	20.676	20.678	2.218
6th	20.665		
7th	20.655		
8th	20.640		
9th	20.630		
10th	20.620		

The total elevation of temperature is

$$20.676 - 18.460 = 2.216°,$$

and the correction is

$$20.676 - 20.620 = 0.056° \text{ for five minutes,}$$

or 0.011° for one minute.

Then

$$2.216 : 0.011 = 0.620 : 0.0031$$
$$2.216 : 0.011 = 1.660 : 0.0083$$
$$2.216 : 0.011 = 2.145 : 0.0107$$
$$2.216 : 0.011 = 2.215 : 0.0110$$
$$2.216 : 0.011 = 2.218 : 0.0110$$

Total.....0.0441

There is then 0.0441 deg. to be added to the difference, 2.216 deg., increasing it to 2.260 deg., which is the corrected difference of the bath temperature, from which the heat of combustion of the substance burned in the calorimeter is calculated.

Regnault and Pfaundler's formula is

$$\Delta tn = \Delta to + K(tn - to);$$

in which Δtn = ascertained variation of temperature from the heating and cooling of the calorimeter for one minute;

Δto = variation at the beginning;

$tn - to$ = loss or gain during the total time of the test;

n = number of minutes of test.

Using the above numbers,

$$K = \frac{0.011}{2.216} = 0.00496.$$

It will suffice, then, to find the total loss or gain to take the sum of all the gains or losses calculated by means of the coefficient K during the whole time of the experiment.

Thus,

$$0.620 \times 0.00496 = 0.0031°,$$

$$1.660 \times 0.00496 = 0.0083°,$$

and so on.

For the full and exact method of correction devised by Pfaundler, see vol. ix., p. 113 *et seq.* of the *Annalen der Chemie und Physik.*

The method of calculating the heat of combustion of a fuel from the results of the calorimeter experiment is explained in detail in the several chapters which follow.

CHAPTER III

CALORIMETERS WITH CONSTANT PRESSURE

THE first calorimeters were of constant pressure; that is, the combustion was carried on at the atmospheric pressure or very near it, and did not vary from the beginning to the end of the experiment. Hence the modifications in the volume of the gases before and after combustion exercised no influence on the observed results.

Rumford, in 1814, was the first who tried to correct external influences. He employed a practical method which has often been used since, consisting in giving the calorimeter bath a temperature in the beginning of the test less than that of the room, and allowing it at the close to attain a temperature in the same proportion above that of the room. His calorimetric apparatus was composed of a copper boiler of several litres capacity, heated by an interior tube through which passed the gaseous products of the combustion. The combustible was burned in a little burner placed under the boiler, and the air used circulated around the heater before passing to the burner, thus preventing any loss of heat by radiation.

Dulong in 1838 used oxygen, and obtained much superior results. His calorimeter consisted of a rectangular copper box, 25 centimetres (about 10 in.) deep, 7.5 centimeters (2.9 in.) wide, and 10 centimeters (3.9 in.) long. It was closed at the upper part by a cover with a mercury seal. The oxygen passed into the calorimeter by a copper tube opening into one of the sides of the box near the bottom. The gases of combustion were drawn into a gas-holder. The apparatus was enclosed in another rectangular box, in which was put 11 litres ($9\frac{2}{3}$ quarts) of water. This was the calorimetric cylinder. The water was kept in motion by an agitator.

The unit chosen by Dulong was 1 gram of water whose temperature was raised 1 deg. Like Rumford, he corrected the tem-

perature observed, but he also noticed that this correction was correct only when the first period was equal to the second. The results obtained by Dulong in 1838 were not published till after his death, in 1843. For hydrogen and carbonic oxide they are but slightly different from the most modern determinations.

CALORIMETER OF FAVRE AND SILBERMANN

In 1852 Favre and Silbermann published their first researches on the quantities of heat generated by chemical action and described their calorimeter.

All rapid-combustion calorimeters and all with constant pressure intended for solid bodies are copied more or less after that of Favre and Silbermann. The principle and mode of execution in their general lines are the same; the form in some details and the material employed for the combustion-chamber have been modified more or less; but the general apparatus and accessories, as well as the method, have remained as Favre and Silbermann left them.

The Favre and Silbermann calorimeter is composed of three concentric copper cylinders (Fig. 2, *B*, *C*, *D*). Cylinder *B* is the calorimeter cylinder; it is silver-plated and polished on the inner surface so as to lessen its emitting power; its capacity is little over 2 litres (3½ pints), being 20 centimetres (about 8 in.) high and 12 centimetres (4¾ in.) in diameter. In the middle is placed the combustion-chamber *A* (Figs. 2 and 3).

The combustion-chamber is of burnished gilt copper, and is shown in Fig. 3. It is a slightly conical vessel, the large opening in which receives a stopper from which is suspended the burner made of a material suitable to that of the substance operated on. The stopper itself carries two tubes, *m* and *n*, the first being an observation tube for the combustion, which is surmounted by a mirror *M*, to allow examination during the burning. The mirror receives light by the tube *m*, which is closed by an athermanous system of quartz, alum, and glass. The other tube, *n*, carries the jet for the oxygen. Tube *b* is closed, or removed during the test with coal, as it is then of no use. Tube *c* serves as the exit for the waste gases of the combustion, which pass through the coil *cc* (Fig. 2) before reaching the

analytical apparatus. This coil is sufficient to cool the gas to the temperature of the bath.

It is impossible to prevent the generation of more or less hydrocarbons and carbon monoxide. The weight of the hydrogen and carbon is determined by causing the gaseous products of combustion to pass through an organic analysis tube, after removing the water and carbon dioxide. For this purpose the exit-tube *c*

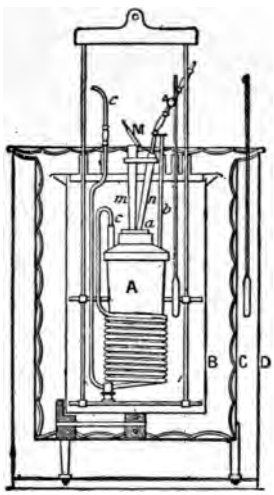

FIG. 2.

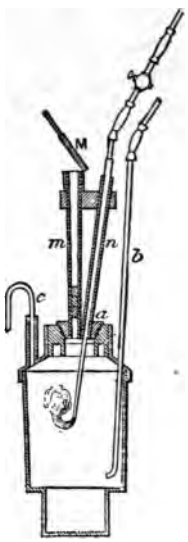

FIG. 3.

Favre and Silbermann Calorimeter.

(Fig. 3) is connected by a rubber tube with a Liebig apparatus, followed by a U-tube of soda-lime.

The gas-current being rather rapid, an absorption apparatus must be used, large and powerful enough to completely free the gas from the carbon dioxide and water before it reaches the red-hot copper oxide. This is done by passing the gases through another U-tube smaller than the preceding, and whose weight should vary only a few milligrams. The gases thus freed pass to the tube of hot copper oxide, where the combustible gases are burned to water and carbon dioxide, which are collected and weighed as usual.

The coal for the experiment must be in pieces; if in powder, the combustion is more difficult, unburned gases escaping in considerable quantities, so that it is rare to obtain a complete combustion, and the cinders almost invariably contain small quantities of coke. To determine these, the capsule and tube are withdrawn from the combustion-chamber, dried and weighed. The coke and the little soot on the sides of the capsule are burned off by calcination in the air and a new weighing made, giving the weight of the carbon and cinder—elements which must be considered in the corrections. From half a gram to a gram of coal may be used.

When the combustion-chamber containing the weighed substance is put into the calorimeter all the parts of the apparatus are connected by rubber joints and tested. A slow current of oxygen * from a gas-holder is passed through the apparatus. The combustible is ignited by a few milligrams of burning charcoal, the joint in the tube being broken for the moment, and immediately without stopping the flow of oxygen. The little glass *M* allows inspection of the combustion, the intensity of which can be regulated by the flow of oxygen from the gas-holder. The temperature shown by the thermometer is recorded each minute to obtain the data necessary for the correction spoken of above (pages 13 *et seq.*).

To calculate the heat-units developed by the combustion the following elements are needed:

1. Weight of the combustible used;
2. Weight of the carbon remaining in the cinders unburned or as black;
3. Weight of the cinders;
4. Weight of hydrogen escaped unburned;
5. Weight of carbon escaped unburned in the gaseous products;
6. Elevation of temperature of calorimeter bath;
7. Correction for heating and cooling caused by external influence on the calorimeter cylinder.

* To prepare the oxygen a copper flask of one litre capacity is used, in which is placed some chlorate of potash, which is then heated by a gas flame. The gaseous current is very regular, except towards the end, when it may become tumultuous. The addition of a small percentage of black oxide of manganese promotes the regularity of the gas generation.

The combustion of the coal by this means is rarely complete; there remain variable quantities of coke mixed with the cinders formed. An uncertainty attends the calorimetric value according as the combustion was slow or rapid, since this small quantity of coke contains more or less hydrocarbons. These differences, however, apply within very close limits, so that no fear need be entertained of large errors therefrom. When a coal, in pieces, has been burned, there remains in the capsule only a few milligrams of coke or unburned carbon. From this we calculate the calorimetric value in calories, using 8080 as the coefficient (heat of combustion of charcoal according to Favre and Silbermann); and in using that coefficient the hydrogen which may exist in the coke is naturally neglected, but this cannot be prevented. The carbon and hydrogen of the combustible gases which escaped combustion are transformed into water and carbon dioxide, and weighed as such. The hydrogen is calculated as in the free state (coefficient 34,500) and the carbon as carbon monoxide (coefficient 2435).

It is evident that these are only approximations, since the hydrogen is not disengaged in a free state, but as a hydrocarbon; and its coefficient (34,500) should be diminished by the heat of formation of this compound, or, in other words, by the heat of combustion of hydrogen and carbon. This correction, however, is not possible; for neither the composition nor state of molecular condensation of such hydrocarbon is known. The same difficulty exists as regards the carbon, and its heat of combination in the carbon compound. There are, then, some uncertainties, but not of much importance, in the determination of the heat of combustion of fuels. These uncertainties the use of the calorimetric bomb has entirely avoided.

ALEXEJEW'S CALORIMETER

The apparatus used by Alexejew was composed of a glass combustion-chamber *A* (Fig. 4), in which he burned the coal previously reduced to fragments. These fragments were placed on a platinum grating in the center of the chamber. The fuel was kindled by means of a platinum sponge placed over it, on which impinged a jet of hydrogen from the gas-holder *M*, opening at *c*, correction for which is, of course, made in the calculation. The

grating containing the fuel was suspended from the glass rod *a*. As soon as the combustion was started the current of hydrogen was cut off by the cock *l*, and the oxygen allowed to flow in through *b*, the waste gases passing out through the coil. If the combustion was interrupted, it was rekindled by the hydrogen and platinum sponge. The hydrogen used was calculated in grams and multiplied by 34,500. The number of calories thus obtained was deducted from that calculated from the rise in temperature of the bath. According to Alexejew, the importance of this correction never exceeded one-half of one per cent, and he never had to rekindle the fuel.

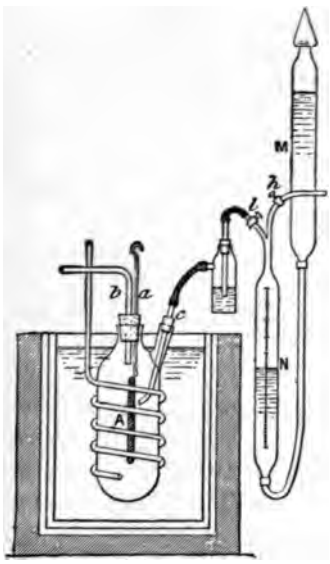

FIG. 4.—Alexejew Calorimeter.

Alexejew did not determine the unburned gases, as experience showed they never exceeded 0.35 per cent. It is impossible, however, to determine the hydrogen of the hydrocarbons if desired, as these would be mixed with the hydrogen used for kindling, part of which may escape combustion. The kindling with hydrogen might, however, be replaced by that with carbon, as in the Favre and Silbermann apparatus.

FISCHER'S CALORIMETER

Fischer made a combustion-chamber of silver 0.940 fine, so that it would be less easily attacked by sulphur, from which the gaseous products of coal are nearly free. He drew off the waste gases at the bottom of the apparatus (Fig. 5), thus avoiding the inconvenience of exit-tubes in the cover of the combustion-chamber. The cooling coil was replaced by a flattened pipe of a certain size. *A* represents the combustion-chamber. The oxygen, purified by passing over potash and then dried, arrived by the tube *a* fastened in the tube of the cover by a rubber joint, and passed by means of the platinum tube *r* into a crucible *z*

of the same metal, containing 1 gram of the fuel. The crucible was covered by a grating, which became red-hot towards the end of the operation. This was intended to burn the waste gases, and the black deposited at the beginning. The gases flowed out at *i*, and after having encircled the outside of the crucible escaped at *b*. The thermometer *t* showed whether the temperature of the gases was the same as that of the bath.

The calorimetric bath contained 1500 grams (3.3 lb.) of water, and was protected against external influences by a wood casing, while the space *C* was filled with glass wool; but this is not necessary. *n* is a brass cover which may be dispensed with. The thermometer *T* is the calorimetric thermometer; *m* is an agitator moved by the string *o*. The value in water of the calorimeter used by Fischer was 113.5 calories. The coal was dried in nitrogen. The carbon dioxide and the unburned carbon were determined.

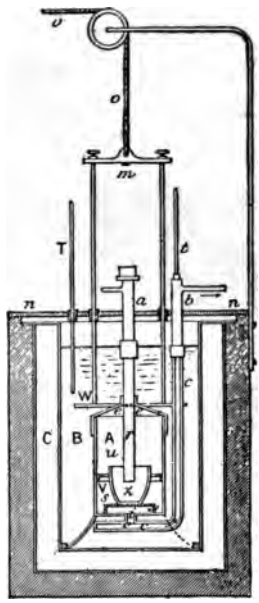

FIG. 5.—Fischer's Calorimeter.

THOMSEN'S CALORIMETER

Thomsen's calorimeter was designed especially for tests of gases and vapors. It is not adapted to tests of solid fuels. It consisted (Fig. 6) of a calorimetric bath of thin brass, with a capacity of some 3 litres (195 cu.in.), protected from radiation by a cylindrical ebonite envelope and a platinum balloon of half a litre (32.5 cu.in.) capacity, in which the gases were burned. These were delivered through the opening at the bottom.

The waste gases passed off through a coil, and a mechanical agitator kept the water in circulation.

The dried gas was delivered with perfect regularity from a mercury gas-holder, sufficient air or oxygen being added to render it free-burning, and enough oxygen was supplied to insure perfect combustion. This was attained by always having 40 to 50 per

cent oxygen in the waste gases. The gases passed off through a carbon dioxide absorbing apparatus.

To reduce to the minimum, or entirely suppress, the correction for temperature Thomsen regulated his gas flow so that the temperature was as much higher than the air at the close of the experiment as it was lower at the beginning. This he easily did by means of his hydrogen supply. If a liquid was tested, it was vaporized and burned in a specially devised burner which allowed complete combustion of almost all compounds not having too high a boiling-point. If too high for heat vaporization, they were carried along by a current of air, oxygen, or hydrogen, as seemed best.

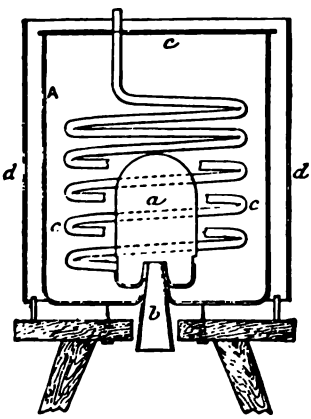

FIG. 6.—Thomsen's Calorimeter.

The water of the calorimeter being weighed, the lower portion was closed with a rubber stopper and by means of an aspirator a pressure of 8 to 12 in. of water was put on the apparatus to test the joints. When ready, the temperature of the bath and the air was noted for some minutes, the gas-holder reading taken, the burner placed in position, and the test commenced. The depression produced by the aspirator was about 0.4 in. during the whole test. The regularity of the working was shown by a gauge registering the pressure. When the temperature had reached the desired point the gas was shut off, the burner removed, and the opening again closed. The aspirator was used to draw dry air, freed from CO_2, through the apparatus to insure removal of all waste gases. The apparatus was then allowed to rest, taking the temperature at short intervals for fifteen minutes. All the data required were then available.

CARPENTER'S CALORIMETER

Prof. R. C. Carpenter devised a calorimeter especially for coal determinations, which is a modification or extension of Thomsen's.

Fig. 7 is a sectional view of his apparatus. It consists of a combustion-cylinder, 15, with a removable bottom, 17, through which passes the tube, 23, to supply oxygen, and also the wires, 26 and 27, to furnish electricity for the igniter. It also supports the asbestos combustion-dishes, 22, used for holding the fuel. At its top is a silver mirror, 38, to deflect the heat. The plug is made of alternate layers of asbestos and vulcanite. The products of combustion pass off through the spiral tube, 28, 29, 30, 31, which is connected with the small chamber, 39, attached to the outer case of the instrument. This chamber has a pressure-gauge, 40, and a small pinhole outlet, 41. Outside the chamber is the calorimetric bath, 1, which is connected with an open glass gauge, 9, 10. Above the water is a diaphragm, 12, used to adjust the level.

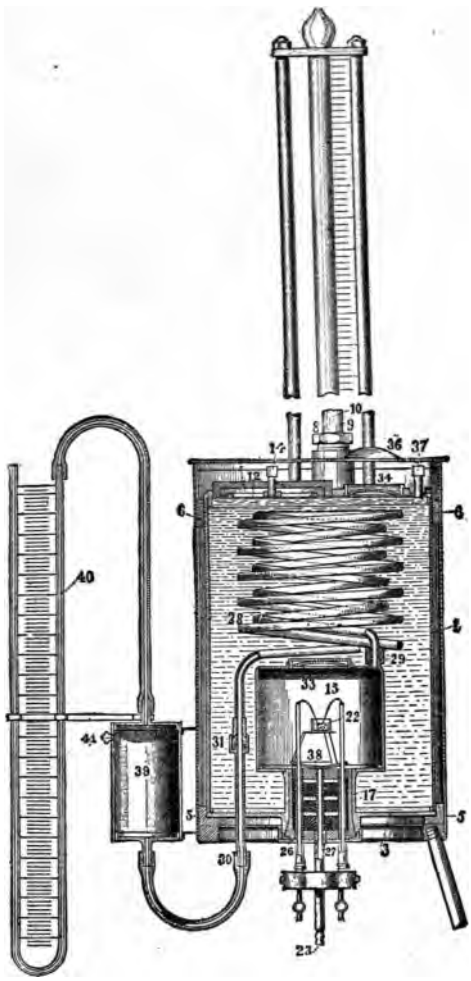

FIG. 7.—Carpenter's Calorimeter.

The calorimeter has an outer nickel-plated case, polished on the outside. The bath holds about 5 lb. of water, and uses about 2 grams of coal at a time. It is thus considerably larger than the bomb, and the charge being larger the time consumed

by the test is longer, being some ten minutes for each gram burned. The entire outside dimensions of the case are 9½ in. high and 6 in. diameter.

In using the apparatus the coal is ground to a powder in a mill or mortar. The asbestos cup is heated to burn off all organic matter and weighed. The sample is then placed in it, and the whole weighed again. This gives the weight of the coal used. Cup and sample are then placed in the combustion-chamber, the platinum igniting wire raised above the coal, and the connections made with the battery. As soon as the heat generated causes the water to rise in the glass tube the oxygen is turned on. Then by pulling down the wires the coal is kindled. At this instant the reading on the glass scale must be taken.

By means of the glasses 33, 34 and 36 the progress of the combustion is observed and as soon as it is finished the scale-reading and the time is noted. The difference between this scale-reading and the one previously made is the "actual" scale-reading.

The correction for radiation is made by allowing the apparatus to stand with the oxygen shut off for a length of time equal to that of the combustion, and taking the scale-reading and the time. The difference between this and the "actual" reading is to be added to the "actual" for the "corrected" reading.

Now, by inspection of the calibration-curve previously prepared, at the point corresponding to the corrected scale-reading will be found the B.T.U. for the quantity burned. The ash is determined by weighing the asbestos cup after the combustion.

The following shows all the calculation needed:

	Grams.
Weight of crucible (asbestos cup)	1.269
Weight of crucible and coal	3.017
Weight of crucible and ash	1.567
Weight of combustibles	1.450
Weight of ash	0.297
Weight of coal	1.747

$$1.747 \text{ grams} \times 0.002205 = 0.003852 \text{ pound.}$$

First scale-reading.....	3.90 in.; time 2 hr. 55 m.
Second scale-reading.....	14.70 in.; time 3 hr. 20 m.
Third scale-reading.....	14.30 in.; time 3 hr. 45 m.
"Actual" scale-reading.....	14.70 − 3.90 = 10.80 in.
Radiation correction.....	14.70 − 14.30 = 0.40 in.
Corrected reading.....	11.20

On the calibration-sheet 11.2 corresponds to 46.25 B.T.U., and 46.25 B.T.U. ÷ 0.003852 = 12,000 B.T.U. per pound.

All air must be removed from the water in the bath. The apparatus must work at a constant pressure, and the pressure for which it is calibrated. A pressure of 10 in. of water has been found satisfactory. Complete combustion is always attained in the asbestos cups.

It will be seen that the use of thermometers is obviated, and also all corrections but one. The apparatus is intended for ordinary every-day work, and will give good comparative results when used according to directions, which must be implicitly followed. The amount of calculation is reduced to a minimum, and there are no delicate parts requiring extra care and adjustment. For the purpose intended, it seems an advance over the others previously used, which could never give more faint approximations to correct results.

W. THOMPSON'S CALORIMETER

W. Thompson devised a calorimeter in which the combustion is started by a jet of oxygen, but the waste gases instead of passing through a coil bubble up through the water of the calorimetric bath. In this apparatus the uncombined gases are naturally neglected. (See Fig. 8.) It is an apparatus, as the inventor says, not intended for scientific researches, but for handy use of mechanics or "for popular use."

a is a galvanized-iron gas-holder containing oxygen; *b*, a stop-cock regulating the flow of water to this holder; *d*, stop-cock for gas; *e*, rubber tube; *f*, level-gauge; *g*, pressure-gauge; *h*, bell-glass covering the platinum crucible *k*, in which the coal is burned; *l* is a support of earthenware suspended from the bell-glass by metal springs, and intended to insulate the crucible and

prevent too quick cooling; m is a glass jar containing 2000 grams (4.4 lb.) of water, forming the calorimetric bath. Water from the jar m cannot enter the bell h while the cock j is closed, and it is opened only when the pressure in the gas-holder is sufficient; n is a glass jar filled with water and surrounding the calorimetric jar, and p is the agitator.

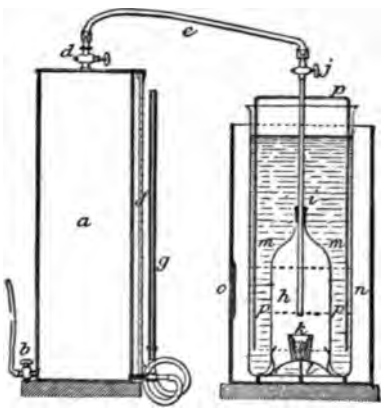

FIG. 8.—W. Thompson's Calorimeter.

One gram of fuel is put into the crucible, and on this is placed a small cotton wick impregnated with bichromate of potash. This is lighted at the instant of putting into the jar, and its combustion aided by the oxygen kindles the fuel.

This is an imperfect apparatus, and will give in most cases only unsatisfactory results.

BARRUS'S CALORIMETER

The Barrus calorimeter is a modification of the one just mentioned. While it requires considerable care in using to get correct results, yet it is one of the simplest and most inexpensive.

As described by Mr. Barrus, "it consists of a glass beaker (Fig. 9) 5 in. in diameter and 11 in. high. The combustion-chamber is of special form, and consists of a glass bell having a notched rib around the lower edge and a head just above the top, with a tube projecting a considerable distance above the upper end. The bell is $2\frac{1}{2}$ in. inside diameter, $5\frac{1}{2}$ in. high, and the tube above is $\frac{3}{8}$ in. inside diameter and extends beyond the bell a distance of 9 in. The base consists of a circular plate of brass 4 in. in diameter, with three clips fastened on the upper side for holding down the combustion-chamber. The base is perforated, and the under side has three pieces of cork attached, which serve as feet. To the center of the upper side of the plate is attached a cup for holding the platinum crucible in which the coal is burned.

To the upper end of the bell, beneath the head, a hood is attached made of wire gauze, which serves to intercept the rising bubbles of gas and retard their escape from the water. The top of the tube is fitted with a cork, and through this is inserted a small glass tube which carries the oxygen to the lower part of the combustion-chamber. This tube is movable up and down, and to some extent sideways, so as to direct the current of oxygen to any part of the crucible and to adjust it to a proper distance from the burning coal."

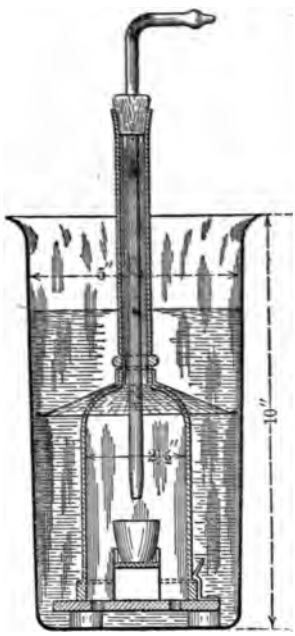

FIG. 9.—Barrus Calorimeter.

The method of working it can be easily seen from the description and cut. Very smoky coals should be mixed with a proportion of non-smoking coal of known calorific value, and when anthracite or coke is burned it should be mixed with a small portion of bituminous coal. In Mr. Barrus's hands the apparatus has given very satisfactory results.

HARTLEY AND JUNKER'S CALORIMETER

Hartley's calorimeter is an apparatus of constant pressure and continued combustion. The gas, measured by a meter, is burned in a Bunsen burner surrounded by a cylindrical copper vessel filled with water, which is constantly renewed. The flow of liquid is such as to avoid much heating and sufficient time is used to increase the temperature so as to have a good thermometer observation. The volume or weight of the water is determined and the thermometer readings taken at such intervals as to obtain an average.

Hugo Junker's modification of the apparatus rendered it more exact. It has been used for some time in Germany and in the United States. It is composed (Fig. 10) of a gas-meter,

a, preceded by a very sensitive regulator *b*. On leaving the meter the gas passes to a Bunsen burner *c*. The products of combustion give up their heat to a calorimetric tube *d*, through which regularly flows a stream of water. The temperature of the gases is regulated by means of a thermometer *e*. In order to keep the flow of water as regular as possible, it flows from the supply-tube *g* into a small reservoir kept at a constant level governed by the tube *h*. The water passes through *i* to the calorimeter and escapes

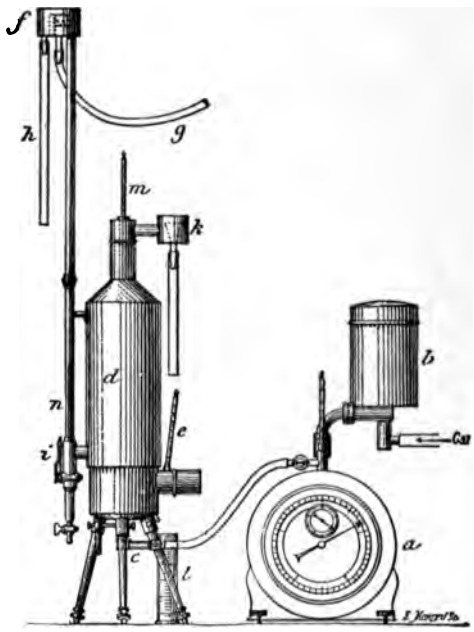

FIG. 10.—Junker Calorimeter.

at *k*, running into the glass in which it is measured or weighed. The graduated tube *l* is to catch the condensed water from the interior of the calorimeter. The thermometer *m* shows the heat of the escaping water, and *n* that of the water entering the calorimeter.

To calculate the calories generated during the combustion proceed as follows:

Measure the quantity of water which runs through it in one minute, take the temperature of the two thermometers, and note

the flow of gas. The heat of combustion per cubic meter of burned gas is obtained by multiplying the volume of water flowing per minute by the difference of the two temperatures and dividing the product by the volume of gas burned per minute.

Thus:

Volume of water flowing per minute....	902.3 cc.
Volume of gas burned per minute.....	2500.0 cc.
Temperature at inlet.....	13.1° C.
Temperature at outlet.....	27.5° C.

$$Q=\frac{902.3\times(27.5-13.1)}{25}=5196 \text{ calories.}$$

The gas tested has a value of 5196 calories per cubic meter.

Since one calorie equals 3.968 B.T.U., and a cubic meter is 35.316 cu.ft., multiplying the calories per cubic meter by $\frac{3.968}{35.316}$ $=0.11235$ will give the B.T.U. per cubic foot.

Multiplying, then,

$$5196\times0.11235=583.8 \text{ B.T.U. per cubic foot.}$$

The above example considered the volume of the water. It is sometimes advisable to consider the weight instead. The following example illustrates this:

Weight of water used during the test....	2000 grams.
Volume of gas burned.....	7.23 liters.
Temperature at inlet.....	14.4° C.
Temperature at outlet.....	36.5° C.

Then

$$Q=\frac{2000\times(36.5-14.4)}{7.23}=6102 \text{ calories per cubic meter,}$$

and

$$6102\times0.11235=685.6 \text{ B.T.U. per cubic foot.}$$

Two causes of error may occur. It is not certain that the combustion of the gas in the burner is regular; indications by gas-meters are not always very sure, the start being capricious. But these do not have much weight in the use of this colorimeter

for industrial purposes, for which it is chiefly designed. The results are very near those obtained by other methods. Stohmann, whose competence in such matters is universally recognized, says that it gives good results.

Bueb-Dessau, to prove the calorimeter, burned hydrogen prepared by electrical decomposition, and obtained after corrections for thermometer and barometer 34,150 calories per kilogram—a difference of 350 calories from the usual number, 34,500.

Prof. Jacobus has determined that there is a constant error due to neglect of latent heat of moisture in products of combustion of -2 per cent in the determinations with this apparatus; otherwise it is quite satisfactory.

LEWIS THOMPSON'S CALORIMETER.

Lewis Thompson's calorimeter has been used in England for some time. It gives only approximate results, but as the errors are of the same kind in each case, the results are comparable, and it has been found serviceable in industrial works where quick and comparative observations are required.

The apparatus (Fig. 11) is composed of a glass calorimeter-bath H containing water, a copper cylinder E in which a mixture of coal and potassium chlorate is placed, and surmounted by the nitrate of lead fuse F. Enclosing this cylinder is a bell D, having a tube C carrying a stop-cock. The cock is closed before putting it in position in the water. K is a cleaner for the tube C, and J is a thermometer.

The fuse is lighted, and the whole quickly put in the jar of water. The mixture of combustible and potassium chlorate soon ignites and burns, all the gases generated being forced out at the bottom of the bell through the perforations, and bubble up through the liquid. After the combustion is finished the temperature is taken and the heat-units calculated.

From 8 to 10 parts of oxidizing mixture is recommended for one of coal; but if the coal is very rich this must be increased to 11 parts, calculated on the crude coal. With pure coal, cinders out, the extreme limits are 11 and 14 parts. It would probably increase the accuracy of the method, if the same quantity of oxidizing mixture was employed, whatever the kind of coal used,

mixing with it inert substances, as silica or ground porcelain, in quantitites varying with the richness of the coal.

Scheurer-Kestner tested this apparatus very carefully, using a great variety of fuels whose heats had been previously ascertained by means of Favre and Silbermann's calorimeter. He found some 15 per cent deficit in the figures, and after correcting by this amount the results varied only a few per cent from those actually obtained. In thirty different kinds of coal tested the average was 1.8 per cent too low.

The use of this calorimeter requires some skill. Its imper-

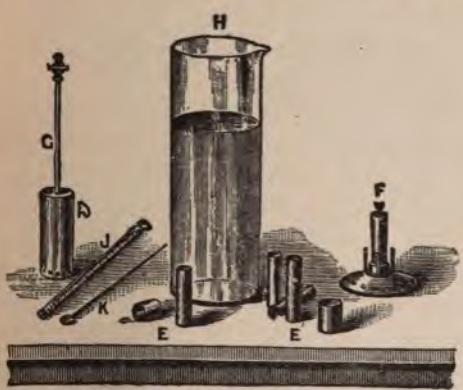

FIG. 11.—Lewis Thompson's Calorimeter.

FIG. 12.—The Calorimeter in Action.

fect insulation requires prompt reading and rapid combustion. Care must be taken to work at temperatures very close to that of the room, as the calorimetric bath is not protected. The proportions of the mixture used vary, not only with each kind of coal, but for each sample, on account of the proportions of cinders. Fat coals require more oxidizer than lean coals, as it is evident an increase in quantity of cinders should require a decrease in oxidizer. But in changing the proportions of oxidizer a certain difference in elevation of temperature is necessarily produced by the heat of solution of the salts left after the combustion. These various causes render its working rather delicate, and always uncertain.

CHAPTER IV

CALORIMETERS WITH CONSTANT VOLUME

THE results obtained with a calorimeter of constant volume are not exactly the same as those obtained with one of constant pressure; but for solid or liquid substances the difference is too small to consider, since the volume, as well as that of the water produced, is inconsiderable in relation to the volume of gas employed. As regards the correction for contraction and expansion of the gases, they also are inconsiderable.

The earliest calorimeter of constant volume is that of Thomas Andrews, who in 1848 published results obtained with a closed calorimeter. The calorimeter was not applicable to solids or liquids; the combustion of the gases was conducted as in a eudiometer, but he did not take all precautions necessary to be certain of complete combustion. Nevertheless, the results obtained for certain gases are remarkable, considering the elementary character of his apparatus and working. The combustion of solids, on the contrary, gave worthless results.

The calorimetric bomb of Berthelot and Vielle seems able to replace advantageously all the other calorimeters as much by its convenience as by its certainty of results.

Since Berthelot and Vielle's original form was published many minor changes have been made in the bomb. All the modern workers seem to prefer some modification of this form, in preference to any of the other and older kinds. There are many points of superiority possessed by the bomb as regards ease and rapidity of working, accuracy, convenience, etc., which have caused it to be universally used.

ANDREWS'S CALORIMETER

In 1848 Andrews published his labors on the heat of combustion of bodies, and notably on that disengaged by combustion of different gases. He used a calorimeter of constant volume, in which the combustion chamber was a copper cylinder (Fig. 13)

weighing 170 grams (6 ounces), of 380 cubic centimeters (about 23½ cubic inches) capacity, and capable of resisting the pressure exerted by the combustion of the same volume of olefiant gas (C_2H_4) with oxygen.

At the upper part, the cylinder had a small conical tube closed by means of a perfect-fitting stopper *b*. A silver wire *a* was fixed in this stopper, and to this was soldered a very fine platinum wire for igniting the gases by a galvanic current. The mixture of gases was prepared as for eudiometric analysis.

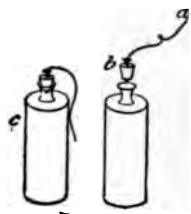

FIG. 13.—Andrews's Calorimeter.

The combustion-chamber was entirely submerged in a glass cylinder filled with water, of which the temperature was regulated so as to compensate approximately for the probable use, and thus avoid corrections for influence of external air. This cylinder was put into another, also of glass. A rotary motion imparted to the cylinder aided circulation in the liquid during combustion, which usually lasted thirty-five seconds.

Andrews also applied his calorimeter to the combustion of solids, but judging from the low results he did not have perfect combustion. The results obtained with some of the gases, on the contrary, are quite reliable, notwithstanding the imperfections of the apparatus.

CALORIMETRIC BOMB OF BERTHELOT AND VIELLE

Of all the calorimeters known to-day, the calorimetric bomb of Berthelot is that which offers the most advantages. Only one operator is needed; the combustion is perfect; the gaseous products need not be analyzed to determine the combustible substance; no weight save that of the substance used is needed; and it is as applicable to solids and liquids as to gases.

While its use requires oxygen under high pressure, this pressure (25 atmospheres) may be readily obtained with a compression-pump, which is easily procured; and at the present time oxygen may be bought sufficiently compressed for the purpose. Berthelot states that as much as 5 or even 10 per cent of nitrogen is allowable, but that the latter limit must not be exceeded.

Mahler used compressed oxygen, and obtained good results with that bought in the Paris market. This gas is furnished in steel tubes and under 120 atmospheres pressure. The cylinders contain sufficient gas to make a large number of experiments before the pressure falls too low, i.e., below 25 atmospheres.

Fig. 14 shows the bomb adjusted ready to place in the calorimeter. Full details of the construction will be found in Berthelot and Vielle's treatise, *Sur la force des métiers explosives*, vol. 1, p. 245.

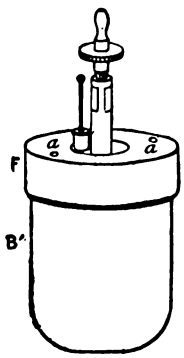

FIG. 14.

Fig. 18 shows the arrangement adopted by Berthelot to burn solids. The cylinder (Fig. 15) is lined with platinum, and constructed so as to resist a pressure of 200 to 300 atmospheres. It is furnished with a tight-fitting head (Fig. 14) fastened exteriorly by a piece of steel (Fig. 16), clamped on the external face of the bomb by a screw-clamp (Fig. 17), which does not form a part of the apparatus as immersed.

The sealing of the bomb results from the adherence of the margin of the head *BB* (Fig. 18), and the interior of the cylinder, and also between the platinum of the head and the platinum of the cylinder. Berthelot made the joint tight with a smearing of vaseline around the opening, being careful not to have a trace on the inside. If no

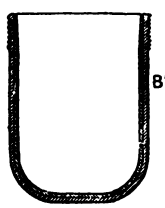

FIG. 15.

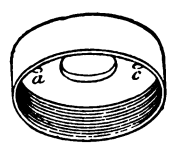
FIG. 16.

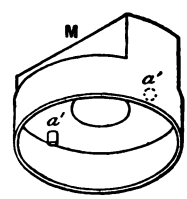

FIG. 17.

bubbles escape on putting it into the calorimetric bath, the joints are tight.

The cover is pierced at the center with a small hole, in which is fitted a tube formed of a hollow screw acting as a cock, and itself provided at the upper end with a circular head. The electric ignition is produced by a platinum wire *E* fitting in an opening

of the removable conical cover. This is prepared (Fig. 18) in advance, and is covered with a layer of gum lac applied in a strong alcoholic solution. When the first coat is dry, a second one is put on and dried in a stove. Berthelot says that the combination of these two coatings, one elastic and soft, the other hard and brittle, resists very well the enormous pressure on the cone. This cone, lightly greased, is put into the conical opening in the bomb cover, and screwed up tight by means of a nut. It is well to protect the base of the cone by a film of mica.

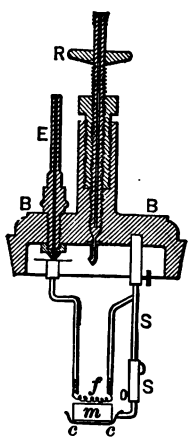

FIG. 18.

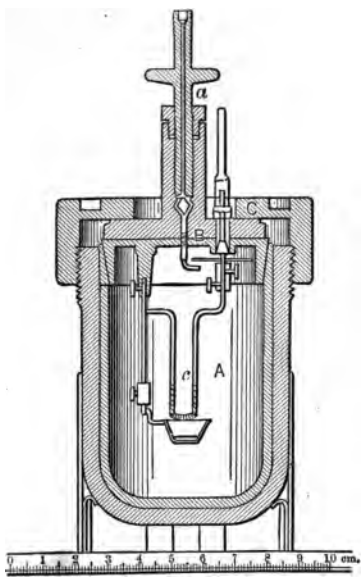

FIG. 19.—Berthelot Bomb.

An electric current passed through *E* (Fig. 18) reddens the spiral of very thin iron wire *f* placed between the platinum wires and one of the supports *SS* of the capsule *cc* containing the substance *m*. This iron wire soon burns and kindles the combustible.

Fig. 19 gives a general and complete internal view.

The iron spiral is formed of an iron wire $^1/_{10}$ millimeter (0.004 inch) thick, rolled up on a spindle. The wire may be weighed, or by taking the same length of wire the same weight will always be used.

The spiral is attached on one side to the cone, and on the other side by means of a platinum wire to the platinum supporting the fuel, taking care that the iron has no straight portions. The support of the capsule or platinum-foil is then fixed in the cover, by aid of the screw, arranging it so that the spiral is directly over the combustible used. The cover is put on, turning it gently to make the contact more perfect. The nut is tightened and the wire carefully screwed up, always using wooden tongs to prevent injuring the bomb.

The form of the bomb is such as to permit filling the calorimeter with the smallest possible quantity of water—a necessary condition that the temperature, and consequently the precision, attain a high degree. For solids and also for coal Berthelot used bombs containing 400 to 600 cubic centimeters (24 to 37 cubic inches), placed in a calorimeter of 2000 grams (4.4 lb.) of water.

To determine the heat of combustion of coal, for instance, it must be previously reduced to powder in order to have a sample whose cinder is known. As all kinds of coal do not burn completely in this state, they are formed into pastilles,* which are weighed and burned. They are put on a platinum grating or foil, placed on the support *SS* (Fig. 18), over which and in contact with it is the iron spiral. At the instant of lighting a slight noise is made, and soon the thermometer begins to rise, showing that the combustion is proceeding.

Compressed oxygen may be introduced either by a pump drawing the gas from a holder or by using a compressed-gas cylinder. In both cases the gas is used without drying, if the combustible contains hydrogen in quantity enough to saturate the gases formed with water produced by its combustion. But if, on the contrary, the combustible has little or no hydrogen, like wood-charcoal for instance, it is immaterial whether the oxygen be dry or not. In this case it is well to use the oxygen moist, or to put a little water in the bomb on the internal walls.

* We obtain very resisting pastilles or briquettes from fat coals by simple compression in a pastille or suppository mould such as used by druggists. With lean coals, or anthracite, the pastilles are too friable and burn incompletely. This is easily remedied by mixing with a small quantity of silicate of soda solution. Several of them should be made at a time, the cinders of some being determined to obtain a mean and the others burned in the bomb. They may contain about 1 gram of pure coal.

By this means a correction for heat of vaporization of water formed by the combustion is obviated.

Oxygen compressed to 120 atmospheres is nearly dry. Berthelot observes: "The oxygen is, in short, actually or nearly dry, and if it contains aqueous vapor the tension is reduced to one-fourth or one-fifth on account of the change in volume of the gas during its passage through the bomb. It may be nearly nullified by the cold produced at the instant of filling the bomb. This admitted, we shall have to account in most combustions for the evaporation of the water produced in the bomb; and this is from 2 to 3.5 calories in a bomb of $\frac{1}{3}$ liter (about 0.6 pint), or 5 to 6 calories in a bomb of 600 to 700 cubic centimeters (37 to 43 cubic inches). These are rather small quantities, it is true; but while they can be neglected in industrial tests, they cannot in rigorously scientific investigations. This correction may, however, be neutralized by putting into the bomb 4 or 5 cc. of water, which should be considered in the calculations."

When oxygen not previously compressed is used and forced in by a pump, Berthelot recommended passing the gas through a large red-hot copper tube filled with oxide of the same metal, so as to burn any oil which may have been taken from the pump.

Operation.—At the laboratory of the College of France the successive operations are as follows:

1. Light the fire to heat the oxygen red-hot;
2. While the gas-holder is filling with oxygen, the fuel is dried;
3. Weigh the fuel;
4. Place the fuel in the bomb;
5. Grease the cover slightly; tighten with the screw;
6. Begin to compress the oxygen by forcing the air out with a few strokes of the piston; pump slowly to prevent heating the pump;
7. Close the stop-cock of the pump; break the connection with the bomb, extinguish the fire, and replace the bomb on its support so as to carry it to the calorimeter room;
8. Pour the water into the calorimetric bath.

The apparatus is allowed to come to equilibrium, and the readings of the thermometer taken for five minutes. The iron coil is then heated by the electric current from a small bichromate battery. It takes fire and kindles the combustible, which gener-

ally burns without smoke or producing any carbon monoxide, as Berthelot has shown.*

The water condensed from the combustion contains small quantities of nitric acid, showing imperfectly purified gas. This may be determined by titration, if accurate results are sought, and calculated as 0.227 calorie per gram of HNO_3. The correction will be very small. A correction for the iron used may be made at the rate of 1.65 calories per gram, this being the heat of formation of the magnetic oxide.

With substances containing nitrogen and sulphur, such as coal, the corrections are more complicated, as a larger quantity of nitric acid is formed and the sulphur forms sulphuric acid. If exactness is sought, it will not be sufficient to make a volumetric test: the sulphuric acid must be determined separately. Generally, however, this estimation may be dispensed with, if for technical purposes only. When, on the contrary, absolutely correct figures are desired, both acids must be considered. In the calculation the nitric acid is reckoned as 0.227 calorie per gram and the sulphuric acid as 1.44 calories per gram.

But these two corrections are really unimportant even with coal, as it contains usually only about 1 per cent of nitrogen or sulphur. One per cent of nitrogen represents $4\frac{1}{2}$ per cent of HNO_3, or 10 calories; one per cent of sulphur represents 3 per cent of H_2SO_4, or 43 calories,—both quite small compared with 7000 to 8000 calories.

Below will be found the details of a complete combustion taken from Berthelot's work.

HEAT OF COMBUSTION OF CARBON

Wood charcoal, purified by chlorine at red heat to remove all traces of hydrogen (Favre and Silbermann's method), is dried at 120 to 140 deg. Cent. (248 to 284 deg. Fahr.), then weighed in a closed tube after cooling in a sulphuric acid desiccator.

* With very fat coals it sometimes happens after a combustion that the platinum shows a black or brown mark, indicating a slight deposit of black or tar which has escaped combustion. Occasionally, also, a trace of tar is found at the bottom of the bomb. These may be prevented by using a grating or perforated plate instead of the foil. This detail must be attended to with a new coal.

0.437 gram carbon; cinders, 0.0028 gram (0.66 per cent); real carbon, 0.4342 gram.

PRELIMINARY PERIOD

0 minute.....	17.360°	3d minute.....	17.360°
1st	17.360	4th	17.360
2d	17.360		

COMBUSTION

5th minute.....	18.500°	7th minute.....	18.820°
6th	18.782	8th	18.818

SUBSEQUENT PERIOD

9th minute.....	18.810°	12th minute.....	18.785°
10th	18.802	13th	18.775
11th	18.795	14th	18.768

Initial cooling per minute,

$$\Delta t_0 = 0.00°.$$

Final cooling per minute,

$$\Delta tn = +0.008°.$$

Correction for cooling,

$$\Delta t = +0.056°.$$

Variation of temperature, uncorrected,

$$18.818° - 17.360° = 1.438°.$$

Value of corrected temperature,

$$1.438° + 0.056° = 1.484°.$$

Value in water of the calorimeter (including oxygen),

$$m = 2398.4.$$

Weight of acid formed;

HNO_3 = 5 cc. of $^1/_{20}$ normal KHO = 0.0173 gram.

Total heat observed, $q_1 = 3.5592$ calories.

Heat of iron coil 22.4
Heat of 0.173 HNO_3, 3.9 } $q_2 = 0.0263$ calorie.

Real heat due to the carbon, 3.5329 calories,

or for one gram, $\frac{3.5329}{0.4342} = 8.1365$ calories,

or per kilogram, 8136.5 calories,
or 14,622.3 B.T.U. per pound.

CHAPTER V

THE CALORIMETRIC BOMB ADAPTED TO INDUSTRIAL USE BY MAHLER

THE calorimetric bomb of Berthelot costs considerably more than can be paid by an industrial laboratory, owing to its large amount of platinum. Mahler replaced the interior platinum of the bomb by an enamel deposited on the steel. The description

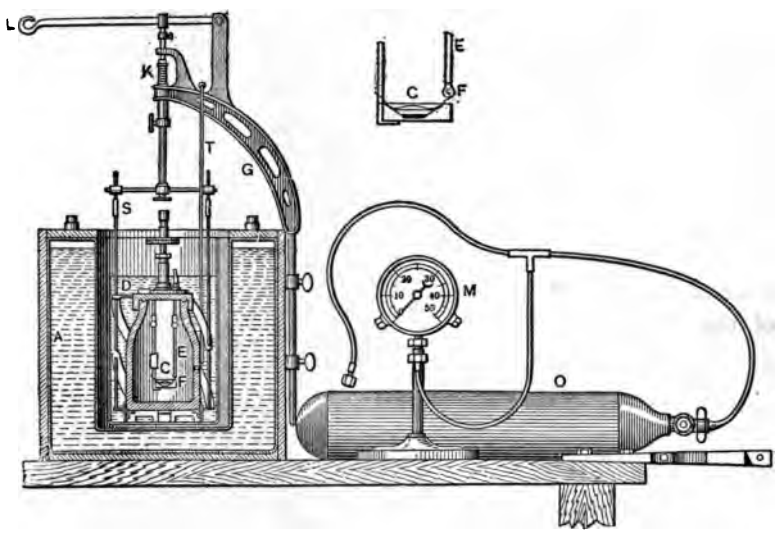

FIG. 20.—Mahler Calorimeter.

given by him in his paper before the *Société d'Encouragement de Paris*, in June, 1892, is as follows:

The apparatus is shown in Fig. 20. It consists essentially of a steel shell, *B*, capable of resisting 50 atmospheres and 22 per cent elongation. This quality was carefully chosen, not only on account of the pressure it must stand, but also as it aids the enameling. The metal is very pure, containing but little phos-

phorus or sulphur. Tensile strength tests are the best criterion of quality.

The bomb has a capacity of 654 cc. (40 cu.in.) at 15 deg. Cent. It is gauged with a balance showing $^1/_{50000}$. The total weight is about 4 kilograms (8.8 lb.) with the accessories.* The metal of the walls is 8 millimeters (about 0.3 in.) thick.

The capacity is greater than Berthelot's, and has the advantage of insuring perfect combustion of carbon in all cases, due to a certain excess of oxygen, even when the purity of this gas as bought is not quite satisfactory. Besides, it is designed to study all industrial gases, even those containing a large percentage of inert gas; hence it must be able to use a sufficiently large quantity to generate the required temperature. The contraction at the top aids in enameling.

The shell is nickeled on the outside, while internally it has a coating of white enamel, resisting corrosion and oxidizing action of the combustion.† It does not, however, offer resistance to the heat, being very thin, and it weighs only about 20 grams (308 grains).

The bomb is closed by an iron stopper made tight by a lead washer (*P*, Fig. 21) and clamped down. This carries a conical-seated stop-cock, *R*, of fine nickel—a metal almost unoxidizable. An electrode well insulated and reaching the interior by a platinum wire runs through the stopper. Fig. 21 shows most of the details. Another platinum wire, also fixed on the cover, supports the platinum disk or foil on which the fuel is placed.

The calorimeter, the non-conducting material, the support for the bomb in the water, and the agitator differ in numerous details from those of Berthelot, and are much cheaper.

The calorimeter is of thin brass, and is quite large on account of the size of the combustion-chamber. It contains 2200 grams (4.85 lb.) of water, thus eliminating the causes of error due to the loss of a few drops by evaporation.‡ The agitator of Berthelot

* Slight modifications have been made in the dimensions of the metal of the bombs made lately by Golaz.

† Prof. W. O. Atwater finds that the enamel chips off in time, and that after about 300 combustions it requires re-enameling. Hempel for coal determinations uses one without any inside enamel.

‡ The evaporation never exceeds a gram per hour.

is supplanted by a very simple and gentle cinematic combination called a drill movement, and which can be worked without fatigue. The source of electricity for ignition is a Trouvé bichromate pile (*P*, Fig. 20) of 10 volts and 2 amperes.

The oxygen used is that furnished by the *Compagnie Continentale d'Oxygène.* This company supplies oxygen free from CO_2, but containing from 5 to 10 per cent of nitrogen. This means of supply simplifies the manipulation; it also obviates the introduction of grease, as happens with oxygen compressed by a pump in the laboratory.*

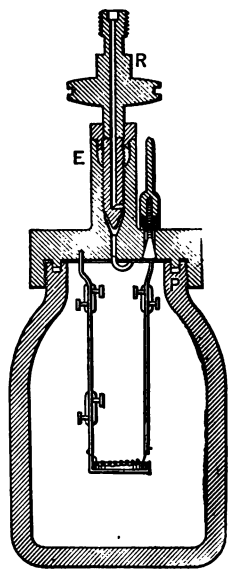

FIG. 21.

The cylinders vary in size, and contain gas at a pressure of 120 atmospheres. The average content is about 1200 liters (about 40 cu.ft.) compressed. They have a uniform top, and hence the copper pipe connecting the bomb with the manometer and the cylinder, once adjusted, will fit all of them.

The method of working, which is simple, is as follows:

Weigh 1 gram of the substance to be tested in the capsule. Fasten a small weighed iron wire (English gauge 26 or 30) to the electrode and to the support of the capsule. Put the end in the bomb and fasten in the cover, which should be held in a vise. Put the conical stop-cock in connection with the oxygen cylinder, and open it carefully so as to allow sufficient oxygen to pass in for the required pressure. Close the cock of the oxygen cylinder, carefully close the conical cock, and break the connection between the bomb and the oxygen cylinder. The substance, especially if coal, must not be too fine, and the oxygen must flow in very slowly to avoid blowing any of it from the capsule.

The bomb thus prepared is placed in the calorimeter, and the thermometer and agitator adjusted. The previously weighed

* This gas is also compressed by pumps at the works.

water, is poured in, agitated a few minutes to restore equilibrium of temperature, and the observations begun.

The experimenter notes the temperature minute by minute for four or five minutes, and determines the rate of the thermometer before the combustion. Then he joins the electrodes, and the combustion begins immediately, almost instantaneously; but the transmission of heat to the calorimeter takes some time.

The temperature is taken one-half minute after kindling, then at the end of the minute, then at each minute to the time when the thermometer begins to lower regularly. This is the maximum. The observations are continued for a few minutes more to ascertain the rate of fall of temperature.

We now have all the elements needed for the calculation, and particularly for the single correction necessary to make under the circumstances. This is the correction for loss of heat before reaching the maximum temperature, which is quite small considering the short time and the large mass involved.

It is not necessary to use the corrections of Regnault and Pfaundler with this apparatus. Newton's law of cooling gives sufficiently accurate results, even in rigorous investigations. Special experiments made to determine the rate of cooling of the water in the calorimeter, when the apparatus was set up as usual, showed that the correction may be regarded as following a simple law, but between comparatively large limits, even under a variation of several hundred grams in amount of water used.

The law* is

1. The decrease in temperature observed after the maximum represents the loss of heat of the calorimeter before the maximum and for a certain minute, with the condition that the mean temperature of this minute does not differ more than one degree from the maximum.

2. If the temperature considered differs more than one degree but less than two degrees from the maximum, the number representing the rate of decrease diminished by 0.005 deg. will be the correction.

The two preceding remarks suffice in all cases with Mahler's

* It is evident that the rule must be modified for apparatus notably different from that used by Mahler.

apparatus. The variation of heat in the first half-minute after kindling may also be corrected by the same law.

The agitator must be worked continually during the experiment, care being taken not to disturb the thermometer.

When through, the conical valve is opened and then the bomb. The inside is washed with a little distilled water to collect the acids formed. The proportion of acids carried away by the escaping oxygen at the opening may be neglected. The acids are determined volumetrically.

When experimenting with substances low in hydrogen and incapable of furnishing sufficient water to form nitric acid, it is advisable to put a little water in the bomb, or hyponitric acid would be formed.

All the data being obtained, we proceed to the calculation of the calorific power Q.

Let T_1, be the temperature of water in calorimeter before ignition of fuel;
T_2, maximum temperature of water in calorimeter after ignition of fuel;
Δ be the observed difference of temperature $= (T_2 - T_1)$;
a, the correction for cooling;
P, the weight of water in the calorimeter;
P', the equivalent in water of the bomb and accessories;
p, the weight of the nitric acid, HNO_3, formed;
p', the weight of the iron;
0.23 calorie, the heat of formation of 1 gram of nitric acid;
1.6 calories, the heat of combustion of 1 gram of iron.

We then have

$$Q = (\Delta + a)(P + P') - (0.23p + 1.6p').$$

In testing coal in this manner the small amount of sulphuric acid formed will be reckoned as nitric acid without serious error, as it will be very small. The heat of the reaction is 1.44 calories per gram of H_2SO_4 formed.

The above details apply to liquids as well as solids. Heavy liquids, such as the heavy oils, tars, etc., are weighed directly into the capsule; but light, easily vaporized liquids must be

placed in pointed glass bulbs. These are put into the capsule, and just before closing the bomb are broken to allow access of the oxygen to the liquid. An almost perfect combustion is obtained in operating with a great variety of materials, nothing but cinders remaining.

To determine the calorific power of gases the exact content of the bomb must be known. It is first filled with gas and the air-pump reduces the pressure to several millimeters of mercury, after which the bomb is again filled with gas, under atmospheric pressure and at the laboratory temperature. The bomb may then be considered full of pure gas.

The method of working with gases is the same as with solids or liquids. The operator must not forget the need of preventing too great dilution with oxygen, as then the mixture will cease to be combustible. With illuminating gas 5 atmospheres of oxygen is sufficient, and with producer gas only one-half atmosphere, as shown by the mercury gauge, is needed.

The gases to be burned are kept in gas-holders over water saturated with gas, or over salt water, according to circumstances, and are saturated with aqueous vapor when they enter the bomb. From the calorific capacity of the different parts is obtained that of the whole, the glass and enamel being omitted.

		Specific Heat.	
Soft steel.....	3945 grams.	3945×0.1097	$= 432.76$
Brass.....	545 "	545×0.093	$= 50.68$
Mercury, platinum, and lead.....	72 "	72×0.03	$= 2.16$
		Sum.....	485.60 grams.

The coefficient 0.1097 is the one adopted by the College of France, from Berthelot and Vielle's experiments, for a steel of similar quality. We have given above (page 12) the calculations relative to the valuation in water. By a direct method of mixing water of different temperatures Mahler found the equivalent to be 470 and 484, and assumed the mean 481.

By the method of burning a body of known composition and heat of combustion he obtained with naphthalin 9688 calories —within $1/2000$ of that given by Berthelot (9692).

The equivalent in water may also be obtained by burning 1 gram of known composition and heat of combustion—naphthalin for instance.* We may also, after Berthelot, burn a substance of fixed composition at two trials with different weights of water in the calorimeter. Two equations are thus formed, from which the heat of combustion of the body used is eliminated, and the heat sought obtained.

In using naphthalin care must be taken to weigh it only after being gently fused in the capsule. It is so light that if not agglomerated some would be blown away by the oxygen. In practice the tests are made rapidly. The water equivalent once determined may be verified by combustion of cane-sugar ($C_{12}H_{11}O_{11}$), for which Berthelot and Vielle found 3961.7 calories. (Use 2 grams for a combustion.)

Examples of Calculations

Mahler gives several types of calculations from his notes, to show the different circumstances which may occur.

Examination of Colza Oil

Elementary analysis showed—

	Per Cent.
Carbon	77.182
Hydrogen	11.711
Oxygen and nitrogen	11.107
	100.000

Weight taken, 1 gram. Calorimeter contained 2200 grams water. Equivalent in water of bomb, etc., 481 grams. Pressure of oxygen, 25 atmospheres.

The apparatus prepared as above was allowed to rest a few minutes to gain equilibrium of temperature. The temperatures were then noted as below:

PRELIMINARY PERIOD

0 minute	10.23°	3 minutes	10.24°
1 "	10.23	4 "	10.25
2 minutes	10.24	5 "	10.25

* This practical method has the advantage of automatically eliminating causes of error.

Rate of variation,

$$a_0 = \frac{10.25 - 10.23}{5} = 0.004°.$$

The electrodes are connected and the combustion begins.

COMBUSTION PERIOD

5½ minutes.....	10.80°	7 minutes.	13.79°
6 "	12.90	8 "	13.84 maximum.*

PERIOD AFTER MAXIMUM

9 minutes.....	13.82°	12 minutes.....	13.79°
10 "	13.81	13 "	13.78
11 "	13.80		

Rate of variation after maximum is

$$a_t = \frac{13.84 - 13.78}{5} = 0.012°.$$

The thermometer observations are now stopped.

The gross variation in temperature was

$$13.84 - 10.25 = 3.59°.$$

The corrections are as follows:

The system lost during the minutes (7, 8) and (6, 7) a quantity of heat corresponding to $2a_t$.

$$2a_t = 0.012 \times 2 = 0.024°.$$

In the half-minute ($5\frac{1}{2}$, 6) it lost

$$\frac{1}{2}(a_t - 0.005) = 0.0035°.$$

But during the half-minute (5, $5\frac{1}{2}$) it gained

$$\frac{1}{2}\, a_0 = \frac{0.004}{2} = 0.002°.$$

* Prof. Jacobus recommends plotting the temperatures and using, not the maximum, but the one at the instant the curve of cooling becomes a straight line. The difference is slight, but important in some cases.

Consequently, the loss for the minutes (5, 6) is

$$0.0035-0.002=0.0015°.$$

Thus that the system had lost, before reaching the maximum temperature,

$$0.024+0.0015=0.0255,$$

which must be added to the 3.59 deg. already found, making the variation in temperature 3.615 deg., neglecting the 4th decimal.

The quantity of heat observed, then, is

$$Q=(2200+481)3.615=2681\times3.615=9.6918 \text{ calories.}$$

From this number must be subtracted—

1. The heat of formation of the 0.13 gram of HNO_3	$0.13\times0.23=0.0299$
2. The heat of combustion of 0.025 gram of iron wire	$0.025\times1.6=0.04$
Total subtraction	0.0699

The final result is, then,

$$9.6918-0.0699=9.6219 \text{ calories,}$$

equivalent to 9,621.9 calories per kilogram or 17,319.4 B.T.U. per pound.

TECHNICAL EXAMINATION OF COAL

The coal taken was a sample of Nixon's coal from South Wales.

Preliminary Period.		Combustion.		After Combustion.	
Minutes.	Degrees C.	Minutes.	Degrees C.	Minutes.	Degrees C.
0	15.20	3½	16.60	7	18.32
1	15.20	4	17.92	8	18.30
2	15.20	5	18.32	9	18.30
3	15.20	6	18.34 maximum	10	18.30
				11	18.26
$a_0=0$		oxygen pressure 25 atmospheres		$a_t=\frac{18.34-18.26}{5}=0.016°$	

Difference of gross temperature	3.140°
Correction (4, 5) (5, 6) 0.016×2	0.032
Correction (4, 3½)	0.005
Correction (3, 3½)	0.000
Corrected difference of temperature	3.177°

or 3.18°.

			Calories.
Heat disengaged	3.18°.	3.18 ×2.681 =	8.5256
Iron wire	0.025.	0.025×1.6 = 0.04	
Nitric acid	0.15.	0.15 ×0.23 = 0.0345	
			0.0745
For one gram			8.4511

or 8451.1 for 1 kilogram, equivalent to 15,212 B.T.U. per pound.

EXAMINATION OF A GAS

Illuminating gas was examined under the following conditions:*

Barometric pressure	761 mm. (29.6 in.).
Tension of aqueous vapor	8 mm. (0.314 in.)
Temperature of laboratory	18.5° C.(65.3° F.).
Volume of bomb	654† cc. (39.9 cu.in.)

Volume of bomb dry at 0° and 760 mm.
606 cc. (37 cu.in.)

The capsule was left in its usual place in the bomb to prevent specks of iron oxide from dropping on the enamel and injuring it.

Preliminary Period.		Combustion.		After Combustion.		Remarks.
Minutes	Deg. C.	Minutes	Deg. C.	Minutes	Deg. C.	
0	18.80	4½	19.50	8	20.07	Pressure of oxygen 5 atmospheres
1	18.80	5	20.00	9	20.06	Grams
2	18.80	6	20.08	10	20.06	Nitric acid...0.06
3	18.80	7	20.81	11	20.055	Iron wire....0.025
4	18.80	maximum		12	20.05	
$a_0 = 0.00$				$a_t = \frac{20.08 - 20.05}{5} = 0.006°$		

* See Kroeker's calorimeter on page 57.

† Exactly 653.9 cubic centimeters.

Gross difference of temperature, Δ	1.28°
Correction as usual, a	0.015
Difference, $\Delta + a$	1.295°

	Calories.	Calories.
Quantity of heat observed, 1.295° ... 1.295 × 2.681 =		3.47189
Heat of HNO_3 formation ..... 0.06 × 0.23	= 0.0138	
Heat of iron wire combustion ..... 0.025 × 1.6	= 0.04	
		0.0538
Heat of combustion of 606 cc. at 0° and 760 mm.		3.41809

or per cubic meter at 760 mm., 5640, or 633.6. B.T.U. per cubic foot.

COMBUSTION USING AN AUXILIARY SUBSTANCE

Sometimes an unconsumed residue is left while determining the heat of combustion of some difficultly burning substances, diamond or graphite for instance. In this case a combustible auxiliary is used to obtain complete burning of the sample. The most convenient to use is naphthalin ($C_{10}H_8$), the heat of combustion of which is exactly known, 9692 calories.

Take petroleum coke, which is nearly allied to graphite. It is mixed with a little naphthalin which has been previously melted at a low heat and then cooled. After cooling the weight of the naphthalin is taken.

The coke analyzed as follows:

	Per Cent.
Carbon	97.855
Hydrogen	0.489
Oxygen	1.196
Nitrogen	0.260
Ash	0.200
	100.000

The data obtained are as follows:

Preliminary Period.		Combustion.		After Combustion.		Remarks.	
Min.	Deg. C.	Min.	Deg. C.	Min.	Deg. C.		Grams.
0	22.05	5½	22.60	10	25.12	Naphthalin	0.034
1	22.05	6	24.20	14	25.05	Iron wire	0.025
5	22.04	7	25.02			Nitric acid	0.080
		8	25.13			Water of calorimeter	2200.
		9	25.14			Equivalent in water	481.
$a_0 = -0.002$		maximum		$a_t = 0.015$			

Difference of temperature	25.14 − 22.04	= 3.100°
Correction for minutes (9, 8), (8, 7), (7, 6)	0.015 × 3	= 0.045
Correction for ½ minute (5½, 6)		= 0.005
Correction for ½ minute (5, 5½)		= 0.001
Corrected temperature difference		3.151°
Then,		
Total heat developed 3.15°	3.15 × 2.681 =	8.4451
From this subtract		
Heat due to naphthalin	0.034 × 9692 = 0.3295	
Heat due to iron wire	0.025 × 1.6 = 0.04	
Heat due to HNO_3	0.08 × 0.23 = 0.0184	
		0.3879
Heat developed by the combustion of the coke		8.0572

or 8057.2 per kilogram, or 14,503 B.T.U. per pound.

When the combustible tested contains hydrogen, it must be remembered that, while the gas in the bomb is dry at the beginning, it is saturated at the close of the experiment. In reality, the latent heat of vaporization of the small quantity of water necessary to be added is inconsiderable. The mean of several tests was 5 in 8500 calories observed, or only $^1/_{1700}$. Still, when we test gases, which cause less marked difference in temperature than solids or liquids, we must to be exact, allow for this heat of vaporization.

It may be asked if any allowance will be made for the heat of the electric current at the moment of kindling. The heat developed by a current with intensity I and electromotive force E is

$$C = \frac{EI}{4.17} t,$$

t being reckoned in seconds. If t was appreciable, this should be considered at least in exact determinations. But, actually, t is very small; the contact is hardly established before the iron is burned and the contact broken.*

Mahler cites two successive tests made on the same coal with his bomb and with the bomb of the College of France, as furnishing proof of the accuracy of his method.

* In exact researches this heat can be easily determined if wished. It will be sufficient to measure the electromotive force in volts. Then put an ammeter in the line which connects the bomb and kindle the combustible as usual. The displacement of the needle shows the intensity of the current under the conditions of the test, and also the time during which the circuit was closed. The formula $\frac{EI}{4.17} t$ will give the quantity of heat sought.

The following results were obtained:

	Scheurer-Kestner at the College of France.	Mahler.
Coal (pure) from Bascoup, Belgium.....	8828	8813

The calculations may be rendered simpler and the observation more rapid, still being exact enough for industrial uses.

Take the equation

$$Q_0 = (\Delta + a)(P + P') - (0.23p + 1.6p'), \quad . \quad . \quad . \quad . \quad (1)$$

arranging the terms in order of the corrections

$$Q_0 = \Delta(P + P') + a(P + P') - (0.23p + 1.6p'). \quad . \quad . \quad . \quad (2)$$

It is clear that the calculation of the calorimetric operation reduces to the determination of a maximum and to one multiplication if we have

$$a(P + P') = 0.23p + 1.6p'. \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Now from the tests made we readily see that whatever value a may take, it increases with the quantity of heat generated in the bomb; it is a little greater when the external air is warmer than when it is cooler—a fact which may be attributed to the influence of evaporation on the cooling of the bath.*

On the other hand, the nitric acid appears to increase with the quantity of heat generated, and tends to offset the correction from a. In short, p' is, within certain limits, at the control of the observer, same as P'. We consider it then possible to arrange once for all so as to have the expression (3) sufficiently close for industrial purposes.

This can be done with Mahler's apparatus. Thus for oil of colza the multiplication $\Delta(P + P')$ gave 9625 calories, which is within $^1/_{3000}$ of the final number obtained after all corrections; with the Nixon's coal we found that $\Delta(P + P') = 8418$ calories,

*The rapidity of cooling in the apparatus employed by Mahler was, according to experiments, between 15° and 20° C.

$$\frac{d\theta}{dt} = 0.005(T - T_0),$$

T_0 being the temperature at which cooling ceases.

which differed $^1/_{250}$ from the correct number; with coal gas the product $2681 \times 1.28 = 3432$ calories, while the corrected result was 3418, or $^1/_{240}$ difference.

ATWATER'S CALORIMETER

Prof. Atwater has considerably modified the bomb, so that it seems to have some advantages for easy working. Fig. 22 gives a sectional view of it in the calorimeter. The steel used is the same as that used in the Hotchkiss guns, and having an unusually high tenacity, seems admirably fitted for the purpose. *A* represents the bomb, *C* the screw-cap *B*, the cover, which is placed on the bomb cylinder and held down by the screw-cap. "The cover is provided with a neck into which fits a cylindrical screw *E*, holding another screw *F*. On the side of the neck is an aperture *G*, between the lower end of *D* and the shoulder. In *D* is a washer of lead, on which the lower ledge of *E* fits. By opening or closing the screw *F* the narrow passage from *z* is opened or closed. The opening is used for admitting oxygen at a high pressure through a narrow passage to charge the bomb. In *B* is an aperture through which passes the platinum wire *H*, which is separated from the metal of the cover by insulating material. Hard vulcanized rubber serves very well for this purpose. Fastened to the lower side of the cover is another platinum rod, *I*, between which and *H* an electrical connection is made with a very fine iron wire. A screw-ring holds the small platinum capsule, in which the substance to be burned is placed. At *KK* are ball-bearings of hard steel to avoid friction in screwing the cap down."

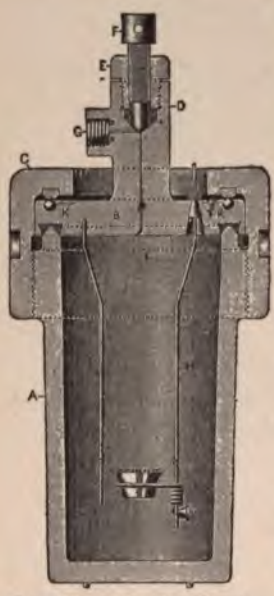

FIG. 22.—Atwater Bomb.

"The large cylinders *N* and *O* are made of indurated fiber, and covered with plates of vulcanized rubber. A stirrer serves

for equalizing the temperature of the different portions of water after the combustion is completed." *

The thermometer used was made by Fuest of Berlin, graduated to $^1/_{100}$ degree, and can be read with a magnifying-glass to $^1/_{1000}$ degree.

The apparatus has been used with success in making the very numerous determinations made by Atwater on the heats of combustion of food-products and other allied organic substances.

KROEKER'S CALORIMETER

Kroeker has recently modified the bomb, making two inlet channels instead of one. By this means he has a current of oxygen gas passing in at one opening and waste gases passing out at the other. It can thus be used for the same purpose that a Junker calorimeter is used, and it is claimed with just as satisfactory results.

The cylinder (Fig. 23) is bored out of a piece of Martin steel, and has a closely fitting screw-plug for a cover, the depth of the screw joint being 25 mm. The walls of the cylinder are 10 mm. thick; external diameter, 72 mm.; internal diameter, 52 mm.; height, 120 mm.; contents, 200 cc. It has four small legs on the under side, which support it and keep it entirely surrounded by the water of the bath. The entire surface is enameled, or preferably platinized. The fuel, in the form of compressed cylinders weighing one gram, is put into the carrier, ignited as usual, and the combustion gases collected and examined.

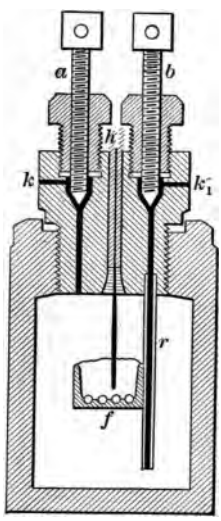

FIG. 23.—Kroeker Calorimeter.

Kroeker had a method of heating the calorimeter bomb in an oil-bath so as to expel all the water of combustion and hydration. He thus obtained data for corrections due to the usual method of determining the water, i.e., considering the water as condensed.

* Prof. W. O. Atwater, in Bulletin No. 21, U. S. Dept. of Agriculture, 1895, pages 124 and 126.

HEMPEL'S CALORIMETER

Hempel's calorimeter is used to a considerable extent in Germany and introduces some new features.

It consists (Fig. 24) of an iron tube into which a bottom about 15 mm. thick and a top about 30 mm. thick are screwed and fastened with hard solder. The chamber capacity is 250 cc. and it will resist a pressure of 25 atmospheres. It is closed by a head-piece (Fig. 25). This has a screw-valve *a*, an insulated wire *d*, and a perforated cup *e* supported by the platinum wires *f f*. The

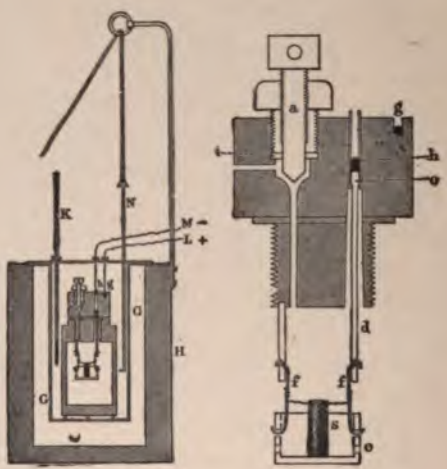

FIG. 24. FIG. 25.

Hempel Calorimeter.

depression *g* contains mercury and serves for battery contact. The wire *d* has a conical enlargement *o* and is wedged into the opening in the head-piece. A lead washer *i* surrounds the valve-rod *a*.

The coal is crushed to powder and then formed into small cylinders by means of a screw-press. This is put in the cup and ignited by the wires *f f*. The oxygen is supplied under a pressure usually about 15 atmospheres.

The apparatus can be made ready in an hour, and the test generally lasts fifteen minutes.

WALTHER-HEMPEL BOMB

The Walther-Hempel bomb is a small cylinder of 33 cc. capacity (Fig. 26), bored out of white cast iron and enameled inside. The walls are 2 mm. thick, and it is strong enough to resist eight times the pressure generally used. The cover is fastened on by means of a screw-clamp, and through it passes the slanting opening *a*, having the electric wire-carrier insulated by a rubber sheath. To the wire at the end of this sheath is attached a platinum wire for kindling the combustible. On the opposite side of the cover is the oxygen tube *d*. The platinum wire *c* is attached to the under side of the cover, and supports the combustible-carrier and its little fire-clay cylinder *e*.

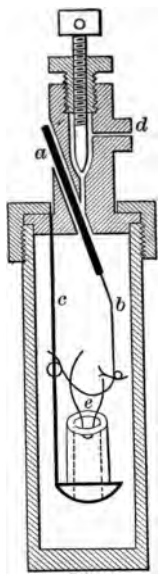

FIG. 26.—Walther-Hempel Bomb.

The fuel is made into small cylinders by compression, put into the fire-clay cylinder, and ignited by the electric spark. The products of combustion are collected and weighed or measured: the water partly in the bomb and partly by means of a calcium chloride tube; the nitric and sulphuric acids are determined by titration with $^1/_{100}$ normal alkali, and afterwards separated if deemed necessary. This bomb is claimed to be capable of use the same as a large one. A full description of it is given in the *Berliner Bericht* for January, 1897.

WITZ'S CALORIMETER

Aimé Witz has modified the calorimetric bomb so as to permit its use for gases. The eudiometric calorimeter, as he calls it (Fig. 27), consists of a steel cylinder *A*, 3.54 in. high, 2.34 in. inside diameter, and 0.08 in. thick, containing 15.55 cu.in. It has two covers, *C*, *C'*, fastened to the cylinder, hermetically sealing it by means of an oiled paper gasket. The upper one carries the spark-exciter *e*. The lower cover has a valve *D*, opening into a chamber about 1 in. diameter. By means of the internal

curved surface of this cover the cylinder can be completely emptied of gas and filled with mercury.

To use the bomb it is filled with mercury and the mixture of air and combustible gas introduced by means of a conical glass gas-holder. The gas escaping from this forces out its bulk of mercury, and after the proper readings it is placed in a calorimeter vessel containing about a liter of water and the gas exploded.

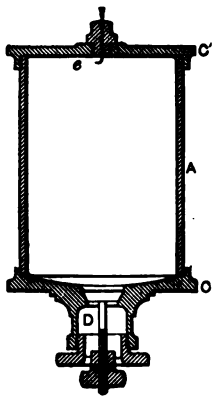

FIG. 27.—Witz's Calorimeter.

Professor Witz has obtained very good results with this apparatus and has used it in many hundred determinations.

ICE-CALORIMETERS

Considerable interest is attached to the ice-calorimeter. It was the first kind used, and although its use in heat determinations has been displaced by the more recent forms, yet there seems to be a tendency on the part of some physicists to return to it.

Its determinations are based on the difference of volume between ice and ice-water. One gram of ice has a volume of 1.09082 cc. (Bunsen), while 1 gram of water at the same temperature has a volume of 1.00012 cc. By the melting of ice using 79.4 gram-calories, a reduction of 0.0907 cc. in volume occurs. Hence 1 calorie is equivalent to a reduction of $^1/_{875}$ cc.

The first use of the ice-calorimeter was by Vilke, a Swedish physicist. Following him came Lavoisier and La Place, who, at the end of the 18th century, carried on their classic researches on heat. Hermann, in 1834, improved their apparatus, and based his determinations on the change in volume of the ice and water instead of on the weight of the melted ice.

HERMANN'S CALORIMETER

Hermann's apparatus (Fig. 28) consisted of a glass cylinder *A*, having a brass screw at the top. On this was fastened a brass cover, sealing it hermetically. This cover carried a thin brass

tube, *B*, running into the cylinder. A graduated glass tube *C* also passed into the cylinder, the divisions being calibrated. By means of the plunger in tube *D* the water-level of *A* is adjusted at the commencement of the test. The whole apparatus is enclosed in a protected box to prevent radiation.

When used, the cylinders *A* and *B* contain ice and water; *E*, containing the thermometer, is filled with the substance to be tested. The proper temperature is given *E*, and it is quickly put into place and allowed to cool to zero.

By the action of the heat of *E* part of the ice is melted, thereby changing the volume of the contents of *A* and the level of the water in *C*.

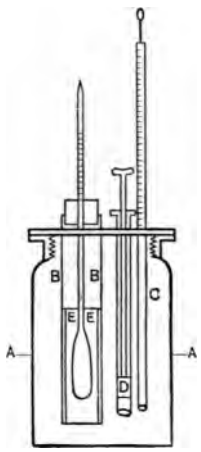

FIG. 28.—Hermann Ice Calorimeter.

HERSCHEL'S CALORIMETER

Herschel devised a calorimeter in 1847 to use in his work on specific heat. It depended on the expansion of the mixture of ice and water.

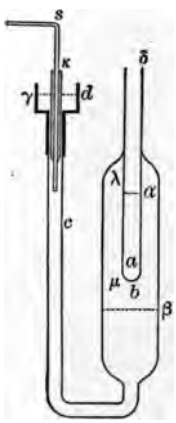

FIG. 29.—Bunsen's Calorimeter.

BUNSEN'S CALORIMETER

Bunsen's calorimeter improved those of his predecessors. A glass tube, *a* (Fig. 29), is fused into a cylindrical bulb, *b*, to which is attached an open bent tube, *c*. At the upper end of this tube is attached a rim top of iron, *d*. The inner tube from *a* to μ and the containing bulb from β to λ are filled with air-free water. The lower part of the apparatus is filled to the iron rim with mercury containing no air. The water in tube *a* is frozen and the whole apparatus placed in a box of snow. A graduated glass tube *s* is passed through a cork into *c*.

To use this calorimeter, the substance to be tested is heated and dropped into *a*, the open end being immediately closed. The change in volume is transmitted and

measured by the mercury. The tube *a* weighs 40 to 50 grams, and about 0.35 gram melts, causing the mercury to move some 400 divisions.

SCHULLA AND WARTHA CALORIMETER

This was described in 1877 in Weidemann's *Annalen*. They placed the calorimeter (Fig. 30) in a metal vessel *J*, containing distilled water and having from 2 to 3 cm. of ice on the sides and bottom. On putting the calorimeter into this vessel the surface of the water was covered with ice spicules which soon melted in the distilled water. The whole was hermetically sealed with a metal cover having two openings for the calorimeter-tube and the tube leading to the measuring-apparatus. It was then enclosed in a wooden box, so that it was surrounded by a thick layer of ice. They weighed the mercury instead of measuring it. In determining the heat of combustion of hydrogen they used purified electrolytic gas and burned it in a special burner. The results were very satisfactory.

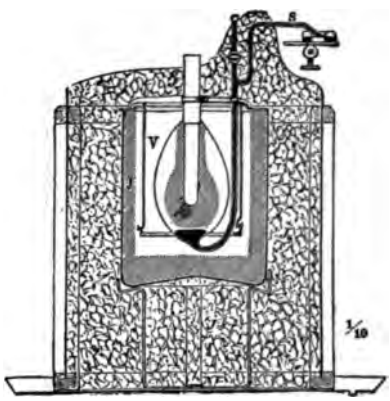

FIG. 30.—Schulla and Wartha Ice Calorimeter.

VON THAN'S CALORIMETER

Von Than made an improvement based on the fact that the melting-point of ice decreases under pressure. The point determined when the ice is under pressure from a column of mercury is too low, and a correction must be made.

His apparatus (Fig. 31) was 19.67 in. high. The inner vessel, *a*, had a capacity of 13.42 cu.in., and was closed with a caoutchouc-lined brass ring. This was fastened to another vessel called the "thermostat," which was simply a Bunsen calorimeter filled with a 2 per cent solution of common salt. This was contained in a

wooden box filled with ice, having a stop-cock at the bottom to draw off the melted water. By this means the apparatus was always ready for use.

With this calorimeter the pressure can be changed so that only melting due to actual heat is possible. In order to do this the side tube of the " thermostat " is connected by a rubber tube

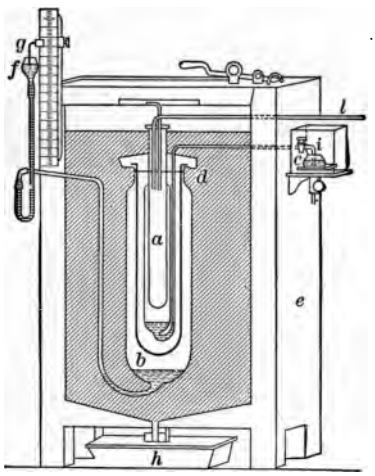

FIG. 31.—Von Than's Ice Calorimeter.

to a vessel, *f*, which can be raised or lowered and the pressure measured.

In determining the heat of combustion of hydrogen von Than worked under constant volume. His burner was made of a glass tube and nearly filled the inner chamber, *a*. The products of combustion passed out through phosphoric anhydride. By weighing this he determined the quantity of water generated. His results were ± 0.04 per cent of the correct amount.

DIETERICI'S CALORIMETER

Dieterici's calorimeter (Fig. 32) is quite large. The inner vessel is nearly 8 in. long. The tube, *S*, through which the mercury flows has a ground joint with a mercury seal. *K* is a wooden box in two parts, filled with ice, containing a porcelain vessel, *P*,

filled with distilled water, which is frozen on the walls. In this is placed the calorimeter, suspended on a fulcrum by means of the tube *S*.

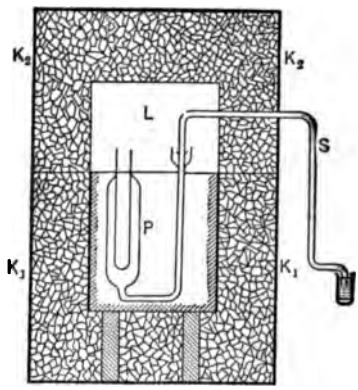

FIG. 32.—Dieterici's Ice Calorimeter.

Dieterici preferred a glass or porcelain vessel to a metal one, as undergoing no change from oxidation.

CHAPTER VI

SOLID FUELS

COAL

AMONG the first careful tests ever made, to determine the heat value of different kinds of coal, were those made in 1843 and 1844 by Prof. W. R. Johnson for the U. S. Navy. He analyzed and tested all the kinds obtained from the United States and England, which were then in use by the navy. At the time they were made the calorimetric determinations were not considered as of the importance they are now, and his tests were limited to determining the evaporative power of the coals. William Kent reviewed them in the *Engineering and Mining Journal*, 1892, showing that up to the time of the experiments nothing comparable with them had been attempted, and that in many respects they compare favorably with work done to-day.

In 1857 Morin and Tresca made numerous determinations of the calorific power of coal and wood, and in 1853 they published a work on "Fuels and their Calorific Power," in which they make many recommendations for more accurate work. They wrote: "It would be extremely important if experiments with the calorimeter could be made on most of the fuels, by methods similar to those used by Favre and Silbermann."

In 1868 such experiments were made by Scheurer-Kestner, and continued by him later with the aid of Meunier-Dollfus. They based their calculations on pure coal, i.e., with moisture and ash deducted. This method, which has been followed by many others, seems very logical, as it facilitates comparison of different fuels by reducing them to the same basis. Enormous errors due to comparison of values not comparable are thus obviated. Coal having 5 per cent impurity has been compared with coal having only 1 per cent, no account being made for the difference, and of course very erroneous and misleading deductions obtained.

It is a simple task for the engineer or the workman even, to determine approximately the proportions of moisture and ash as given on the grate. Knowing these proportions and the heat of combustion of the pure coal, they can render a statement of the practical working. If, on the contrary, the experimenter is limited in such a way that he neglects the composition of the coal, it is impossible to make a conjecture as to its intrinsic or comparative value; still less can he judge of it as a steam generator.

In 1879 Bunte made some experiments at Munich, using a special apparatus devised by him for the occasion, which was part calorimeter and part boiler. The tests were published in Dingler's *Polytechnisches Journal.* Some of the results are included in the tables of this book.

The manner in which a coal acts under heat in a closed vessel is a most important indication, taken in connection with its elementary composition. Gruner gave his opinion that the real value of a coal could be determined better from its proximate than from the ultimate composition. Speaking of the Loire coal, he says:

"The proximate analysis, which consists in distilling coal in a retort and incinerating the residue, allows direct valuation of the agglomerating power as well as the nature and proportion of the ash."

Gruner * formed the table on page 67, based on the quantity and nature of the coke furnished and the calorific power.

Heating Value of American Coals. The tables of heating values of American coals which follow are taken from Bulletin No. 22 of the United States Bureau of Mines in which is given over 3000 analyses and results of calorimetric determinations. The tables as presented were compiled from those in the Bulletin by William Kent, and published in a paper at the June, 1914, meeting of the American Society of Mechanical Engineers, and in the second edition of his "Steam Boiler Economy," from which they are here reprinted by permission.

For these tables Mr. Kent has selected 155 analyses of coals from different states, showing practically the extreme range of composition of heating value of the coals of each of these states, whenever a sufficient number of coals of such states are given in

* Annales des Mines, 1878, Vol. IV.

GRUNER'S CLASSIFICATION OF COALS

Classes or Types of Coal Properly so Called.	Per Cent Coke to Pure Coal.	Per Cent of Volatile Matter in Pure Coal.	Nature and Appearance of Coke.	Calorific Power, Actual. Calories.	Industrial Calorific Power. Water at 0° C. Vaporized at 112° C. per Kilo of Pure Coal Burned, in Kilograms.
1. Dry coals with long flame,	55 to 66	45 to 40	Powdery or slightly coked.	8000 to 8500	6.7 to 7.5
2. Fat coals with long flame (gas coals),	60 to 68	40 to 32	Completely agglomerated, oftener caked, but porous.	8500 to 8800	7.6 to 8.3
3. Fat coals, properly so called ("blacksmith" coals),	68 to 74	32 to 36	Caked and more or less puffy.	8800 to 9300	8.4 to 9.2
4. Fat coals with short flame (coking coals),	74 to 82	26 to 18	Coked, compact.	9300 to 9600	9.2 to 10
5. Lean coals or anthracite,	82 to 90	18 to 10	Slightly coked, oftener powdery.	9200 to 9500	9.0 to 9.5

the bulletin. The most important items of the ultimate and proximate analyses were tabulated, viz., the S, H, C, O, and N of the ultimate analysis as referred to the combustible (coal free of moisture and ash), also the volatile matter, the moisture and the ash of the proximate analysis, the moisture and ash being referred to the coal as received, and the volatile matter being referred to the combustible. (See Table 1.) The fixed carbon referred to combustible is 100 per cent minus the volatile matter of the combustible, and referred to coal as received it is 100 per cent minus the sum of moisture, ash and volatile matter. The results as given in the bulletin were calculated to three different bases: (1) as received, (2) dry coal, (3) ash- and moisture-free (commonly called combustible); and in many cases to a fourth basis, ash-, moisture- and sulphur-free. For the purpose of comparison, however, other information was desired, such as the B.T.U. per lb. of coal air-dry, ash-free, and air-dry, ash- and sulphur-free not contained in the bulletin. These omitted items were calculated and tabulated, but it should be stated that the

figures which were obtained relating to B.T.U. calculated to the sulphur-free basis, are probably too high in many cases of high sulphur coals.

Having thus tabulated the results, the questions to be solved are (1) how shall the coals be classified; (2) what relation does the heating value of the coals bear to the chemical composition.

In studying the 155 coals, Mr. Kent first plotted the B.T.U. per lb. of combustible with the results which are shown graphically in Fig. 34. This plotting shows that all the coals of the Appalachian field come close to the original curve drawn by him in 1892 from Mahler's tests of European coals, when the volatile matter in the combustible is 35 per cent or less. For coals higher in volatile matter, and for Western coals generally, the heating value varies over a wide range and appears to have no relation to the volatile matter, but each district has a law of its own. The Illinois coals are all found within the small area shown by dotted lines. Perhaps the most important conclusion from Fig. 34 is that all the semi-bituminous coals of the Eastern states, and those from the Western states and Alaska with a very few exceptions, have a heating value per pound of combustible that is very close to 15,750 B.T.U. With bituminous coals and lignite containing over 36 per cent of volatile matter in the combustible there appears to be no law connecting the heating value with the percentage of volatile matter, and the plotting is not continued beyond 44 per cent.

As many of the coals high in volatile matter are also high in sulphur, it was attempted to find if high sulphur was the cause of some of the variation of the heating value, but the results are negative. When the heating value per pound of combustible is converted for sulphur by the usual method, by subtracting 4050 B.T.U. per lb. S, and dividing by 1 minus (per cent S ÷ 100) the value thus found is often far higher than the heating value per pound of combustible of coals of the same districts that are low in sulphur. Lower values for these coals might be found if they were converted by the "unit coal" method of Parr and Wheeler (Bulletin 37, 1909, of the Illinois University Engineering Experiment Station), viz.:

$$\text{B.T.U. per lb. unit coal} = \frac{\text{Indicated dry B.T.U.} - 5000\,\text{S}}{1.00 - (1.08\ \text{ash} + 0.55\,\text{S})}.$$

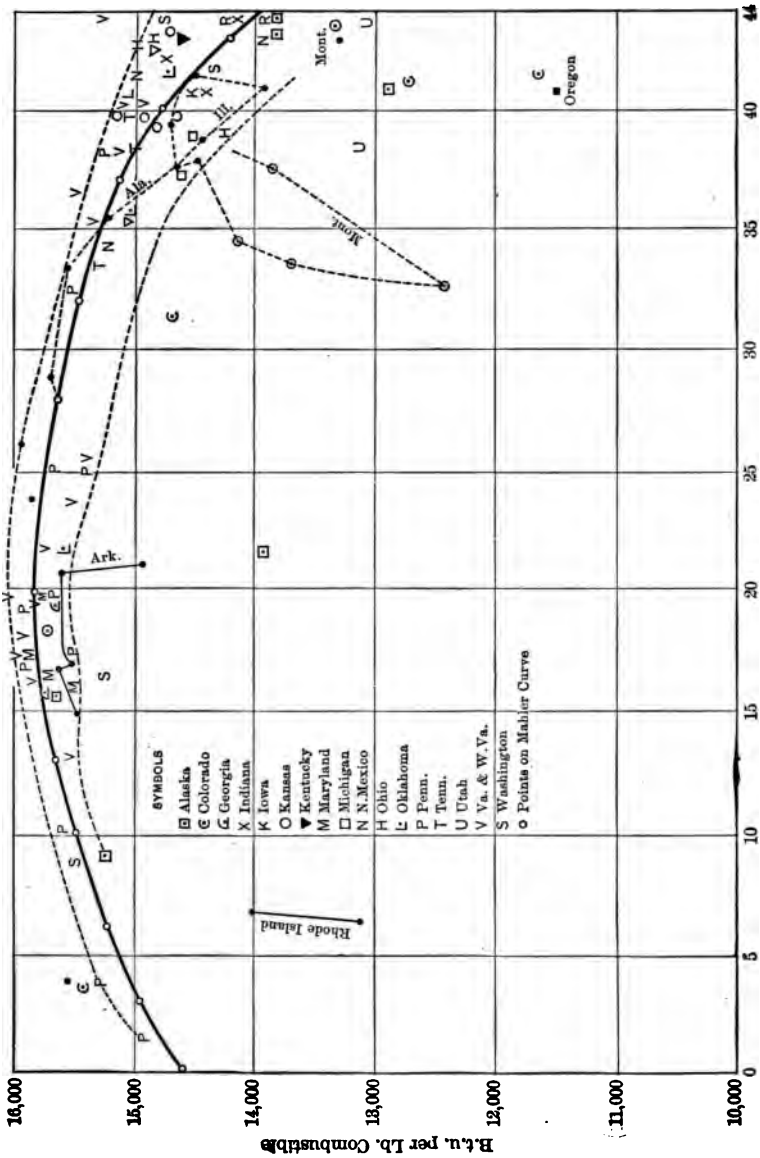

FIG. 34.—Relation of Heating Value to Percentage of Volatile Matter in the Combustible.

Fig. 35 shows the result of plotting the heating value per pound of air-dry coal and ash- and sulphur-free, against the percentage of moisture in such coal, for those cases in which the moisture does not exceed 11 per cent. The results indicate that this method may prove to be of considerable importance when it is applied separately to the coals of different states or districts, especially the bituminous coals of the Middle West. The high position of the Kansas coals and of one of the Missouri coals may be due to the error of the common method of correcting for sulphur.

The average results shown in Fig. 35 correspond approximately to the following formula:

B.T.U. per lb. air-dry coal, ash-free $= 16{,}400 - 800M_a$, for semi-bituminous coal;

$= 15{,}300 - 240M_a$, for bituminous coal;

in which M_a is the percentage of moisture remaining in the coal after air-drying, referred to the coal free from ash. That is,

$$M_a = \frac{M - L}{100 - (A + L)},$$

in which M and A are respectively the moisture and ash in the coal as received, and L is the loss on air-drying, figured as a percentage of the coal as received.

After studying the coals by the method of plotting as described, Table 2 was constructed, in which a revised classification is attempted. The extreme differences in B.T.U. per lb. between the B.T.U. per lb. given and those that result from calculation by Dulong's formula, by the Mahler curve, and by the moisture formulæ for air-dry, ash-free coal, are given in the table on page 85. The extent of these differences suggests that in some cases the calorimetric determinations, or the analyses, or both, may be in error, and indicates the necessity for thoroughly checking the loss in air-drying, the moisture determinations of the air-dried coal, the analyses, proximate and ultimate, and the calorimetric work.

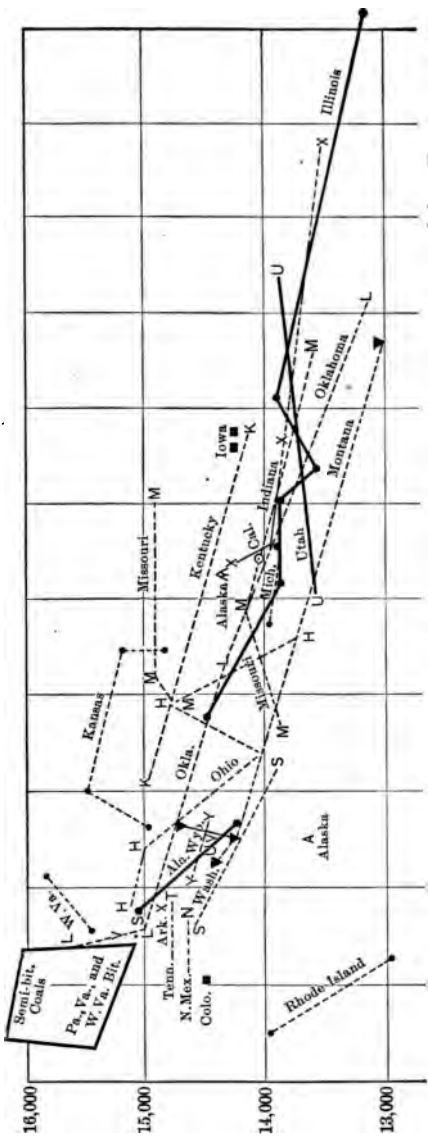

FIG. 35.—Relation of Heating Value to Moisture in Air-dry Coal, Ash- and Sulphur Free

TABLE 1

ANALYSES AND HEATING VALUES OF AMERICAN COALS

(Condensed from Bulletin No. 22, U. S. Bureau of Mines)

Page of Bulletin 22.	Volatile Matter, Per Cent of Combustible.	Composition of the Combustible.					B.T.U. per Pound Combustible.	As Received.				Air-dry, Ash-free.		
		S	*H*	*C*	*N*	*O*		*M* Moist.	*L* Loss on Air Drying.	*A* Ash.	B.T.U.	$F = 100 - (A + L)$	$\frac{\text{B.T.U.}}{F} = \text{B.T.U.}$	$\frac{M - L}{F} = M_1$
Alabama														
36	28.8	0.59	5.32	88.05	1.59	4.45	15,757	3.08	2.0	3.75	14,681	94.25	15,577	1.15
37	27.9	1.58	5.28	88.07	1.65	3.42	15,620	2.38	1.5	4.88	14,487	93.62	15,475	0.94
38	33.4	1.13	4.99	85.09	1.80	6.99	15,590	2.18	1.0	2.79	14,816	96.21	15,400	1.23
39	35.3	1.07	5.36	85.18	1.39	7.00	15,214	3.83	2.2	5.48	13,799	92.32	14,947	1.77
41	37.7	1.37	5.07	81.28	1.83	10.45	14,467	3.95	1.7.	14.59	11,785	83.71	14,078	2.69
Alaska														
41	44.2	1.83	5.70	77.50	0.86	14.11	13,838	7.06	5.2	21.78	9,846	73.02	13,484	2.55
41	40.8	0.94	5.09	74.32	0.82	18.83	12,964	10.77	6.5	14.87	9,641	78.63	12,261	5.42
41	15.5	1.29	4.37	89.78	1.54	3.02	15,651	5.14	4.6	5.00	14,065	90.40	15,559	0.60
42	8.8	0.73	3.68	89.63	1.92	4.04	15,203	7.43	6.2	14.36	11,891	79.44	14,968	1.55
43	21.7	10.76	4.51	78.10	1.35	5.28	13,945	5.71	2.7	34.15	8,386	63.15	13,279	4.77
Arkansas														
48	14.8	2.33	4.16	89.34	1.60	2.57	15,496	2.36	1.1	12.08	13,259	86.82	15,272	1.45
49	16.7	3.16	4.21	89.28	1.66	1.69	15,624	2.77	2.2	9.07	13,774	88.73	15,525	0.86
49	52.1	0.96	5.11	71.43	1.33	21.17	12,497	39.43	25.1	9.71	6,356	65.19	9,750	22.00
50	21.0	1.43	4.76	85.61	1.76	6.44	14,945	5.26	4.2	24.81	10,451	70.99	14,722	1.77
51	17.0	3.57	3.87	89.57	1.74	1.25	15,530	3.21	2.4	9.29	13,588	88.31	15,387	0.92
51	20.7	1.47	4.50	88.05	1.71	4.27	15,602	3.24	2.1	12.61	13,129	85.29	15,393	1.34

CALIFORNIA														
53	53.5	4.62	5.86	71.73	1.00	16.79	12,890	18.51	10.4	15.49	8,507	74.11	11,478	10.95
53	53.8	4.80	6.35	76.03	1.35	11.47	14,336	6.95	2.2	6.23	12,447	91.57	13,593	5.19
COLORADO														
54	41.4	0.44	5.17	76.05	1.37	16.97	11,619	19.65	13.0	6.00	8,638	81.00	10,664	8.21
55	45.5	0.51	5.07	76.22	1.68	16.52	13,239	19.28	5.5	4.70	9,064	89.80	10,094	15.35
55	41.1	0.39	5.18	74.97	1.46	18.00	12,746	17.32	9.9	4.64	9,947	85.46	11,638	8.68
55	31.3	0.72	5.17	83.35	1.38	9.38	14,681	2.64	1.7	5.21	13,529	93.09	14,533	1.01
63	3.6	0.87	3.25	93.34	1.22	1.32	15,413	2.70	1.7	5.83	14,099	92.47	15,247	1.08
70	33.7	0.56	5.62	83.83	1.22	8.77	15,559	2.28	1.5	9.16	13,781	89.34	15,423	0.87
75	23.8	0.58	5.02	88.05	2.01	4.34	15,849	0.96	0.2	8.62	14,330	91.18	15,716	0.83
76	25.8	0.72	5.27	89.80	1.92	2.29	15,939	3.07	1.8	9.16	13,990	89.04	15,712	1.43
GEORGIA														
82	19.4	1.55	4.77	86.39	1.33	5.96	15,653	3.80	3.2	14.49	12,791	82.31	15,540	0.74
IDAHO														
82	50.9	4.77	....	.....	....	....	16,457	34.28	24.0	13.38	8,613	62.61	13,757	16.42
ILLINOIS														
83	46.0	6.33	5.51	76.23	1.40	10.53	14,263	11.35	5.9	13.40	10,733	80.70	13,300	6.75
83	41.4	1.36	5.22	79.80	1.60	12.02	14,492	8.12	3.6	8.63	12,064	87.77	13,745	5.15
84	37.4	1.14	5.14	83.51	1.75	8.46	14,621	10.72	5.6	9.36	11,686	85.04	13,742	6.02
89	40.8	5.55	5.38	75.51	1.54	12.02	13,921	14.43	9.8	13.28	10,064	76.92	13,084	6.02
89	46.2	6.02	5.44	77.08	1.37	10.09	14,155	13.20	4.4	12.53	10,514	83.07	12,657	10.59
90	40.0	2.82	5.30	80.42	1.72	9.74	14,818	7.81	5.8	8.38	12,418	85.82	14,470	2.34
92	39.3	3.10	5.36	80.89	1.62	9.03	14,724	8.86	5.8	11.66	11,702	82.54	14,177	3.71

TABLE 1—*Continued*

ANALYSES AND HEATING VALUES OF AMERICAN COALS

Page of Bulletin 22.	Volatile Matter, Per Cent of Combustible.	Composition of the Combustible.					B.T.U. per Pound Combustible.	As Received.				Air-dry, Ash-free.		
		S	*H*	*C*	*N*	*O*		*M* Moist.	*L* Loss on Air Drying.	*A* Ash.	B.T.U.	$F = 100 - (A + L)$	$\frac{\text{B.T.U.}}{F} = \text{B.T.U.}$	$\frac{M - L}{F} = M_1$
Indiana														
93	40.9	2.88	5.48	80.60	1.54	9.50	14,492	16.91	13.1	17.37	9,524	69.53	13,698	5.48
95	42.2	1.78	5.37	80.89	1.41	10.55	14,746	12.11	3.5	6.83	11,952	89.67	13,329	9.60
97	47.3	6.60	5.57	76.68	1.19	9.96	14,305	7.88	3.7	14.20	11,146	82.10	13,576	5.01
99	44.8	6.73	5.48	76.58	1.52	9.69	14,089	13.18	8.5	15.63	10,030	75.87	13,220	6.17
Iowa														
99	47.5	5.69	5.35	78.03	1.20	9.73	14,305	14.08	4.5	10.96	10,723	84.54	12,684	11.33
100	51.2	8.53	5.52	75.83	1.16	8.96	14,206	13.88	9.8	14.01	10,244	76.19	13,445	5.35
100	40.6	6.64	5.13	78.96	1.24	8.03	14,555	8.24	3.2	16.00	11,027	80.80	13,647	6.24
Kansas														
101	44.2	9.94	5.54	77.59	1.29	5.64	14,724	6.95	3.5	12.19	11,905	84.31	14,121	4.09
101	39.8	6.68	5.44	81.21	1.41	5.26	15,167	2.50	.....	12.45	12,900	87.55	14,734	2.86
101	39.8	5.22	5.40	82.08	1.32	5.98	14,922	4.99	1.3	12.97	12,242	85.73	14,269	4.30
102	39.5	4.93	5.33	81.06	1.41	7.27	14,809	9.04	7.1	15.72	11,142	77.18	14,436	2.49

KENTUCKY

104	44.0	4.29	5.50	79.60	1.71	8.90	14,657	7.92	2.2	10.06	12,022	87.74	13,702	6.52
105	55.5	1.38	7.13	82.59	1.33	7.57	15,800	2.36	1.5	10.49	13,770	88.01	15,646	0.92
105	57.0	1.15	7.46	82.31	1.47	7.61	16,013	1.70	0.4	9.31	14,251	90.29	15,784	1.44
107	35.3	0.58	5.32	84.75	1.30	8.05	15,328	3.41	2.0	5.73	13,928	92.27	15,095	1.64
107	43.5	5.64	5.10	80.26	1.54	7.46	14,836	5.27	2.8	14.18	11,950	83.02	14,394	2.98

MARYLAND

108	16.5	1.13	4.67	89.48	1.91	2.81	15,710	2.70	1.9	8.80	13,910	89.30	15,577	0.90
110	16.0	1.02	4.62	89.85	1.97	2.54	15,640	3.20	2.2	6.70	14,100	91.10	15,478	1.10
110	19.7	0.94	4.85	89.58	1.62	3.01	15,826	3.42	2.7	7.09	14,162	90.21	15,699	0.80
111	17.5	0.98	4.76	89.79	2.00	2.47	15,850	2.60	2.0	6.80	14,360	91.20	15,746	0.66

MICHIGAN

113	38.8	1.53	5.56	81.91	1.46	9.54	14,499	11.91	7.9	6.84	11,781	85.26	13,818	4.70
113	37.1	1.11	5.40	81.52	1.46	10.51	14,603	11.55	6.5	3.25	12,442	90.25	13,786	5.59

MISSOURI

114	44.8	5.16	5.51	78.50	1.30	9.53	14,351	14.59	11.1	13.91	10,260	74.99	13,682	4.65
114	47.3	4.85	5.67	77.51	1.29	10.68	14,202	15.36	9.5	10.99	10,460	79.51	13,156	7.37
115	44.6	4.96	5.26	76.55	1.40	11.83	13,892	17.30	15.2	23.38	8,240	61.42	13,416	3.42
116	50.8	6.33	5.61	79.08	1.25	7.73	14,679	10.36	7.4	12.33	11,347	80.27	14,136	3.69
120	45 3	9 45	5.51	77.49	1.27	6.28	14,476	11.40	8.5	15.78	10,541	75.72	13,921	2.83
122	50.2	6.21	5.78	81.05	0.84	6.12	15,134	12.67	7.7	4.83	12,487	87.47	14,276	5.68

TABLE 1—*Continued*

ANALYSES AND HEATING VALUES OF AMERICAN COALS

Page of Bulletin 22.	Volatile Matter, Per Cent of Combustible.	Composition of the Combustible.					B.T.U. per Pound Combustible.	As Received.				Air-dry. Ash-free.		
		S	*H*	*C*	*N*	*O*		*M* Moist.	*L* Loss on Air Drying.	*A* Ash.	B.T.U.	$F = 100 - (A + L)$	$\frac{\text{B.T.U.}}{F} = \text{B.T.U.}$	$\frac{M - L}{F} = M_1$
								Montana						
124	33.3	12.99	4.77	74.61	0.81	6.82	13,693	3.04	1.6	37.77	8,105	60.63	13,368	2.37
125	44.4	1.72	5.11	71.06	1.67	20.44	13,338	10.05	2.0	6.02	11,194	91.98	12,170	8.75
125	43.7	2.00	5.41	74.92	1.80	15.87	13,162	9.67	4.1	8.02	10,832	87.88	12,324	6.34
125	37.5	0.86	5.43	76.13	1.37	16.21	13,865	9.76	3.7	16.42	10,235	79.88	12,813	7.58
126	34.3	4.86	4.86	79.90	0.88	9.50	14,134	3.51	1.6	19.50	10,881	78.90	13,791	2.42
127	32.6	2.88	4.03	76.11	0.84	16.14	12,438	10.88	5.4	26.88	7,742	67.72	11,432	8.09
129	69.0	1.86	3.78	69.52	1.37	23.47	11,900	30.00	19.3	11.90	6,914	68.80	10,049	15.55
133	39.6	0.60	5.67	82.75	1.21	9.77	14,681	5.77	3.8	10.57	12,281	85.63	14,342	2.30
133	18.3	0.96	4.29	90.39	1.43	2.93	15,721	2.05	1.5	8.31	14,092	90.19	15,625	0.61
135	54.1	0.67	3.45	68.11	1.13	26.64	10,211	24.59	4.3	14.61	6,208	81.09	7,656	25.02
								New Mexico						
137	41.5	0.74	5.75	82.89	1.83	8.79	14,875	2.78	1.4	14.57	12,294	84.03	14,630	1.64
138	34.4	0.96	5.67	85.32	1.12	6.93	15,221	2.45	1.8	17.40	12,200	80.80	15,099	0.80
139	44.3	0.68	5.53	79.54	1.55	12.70	14,539	5.02	2.4	12 00	12,064	85.60	14,093	3.06
140	42.8	0.78	5.51	78.43	1.28	14.00	13,939	12.29	1.6	6.99	11,252	91.41	12,309	11.70
141	46.8	2.38	5.59	74.48	1.86	15.69	13,322	15.79	7.6	9.37	9,970	83.03	12,008	9.87

North Dakota

142	49.8	1.16	....	.....	....	.....	11,398	43.78	35.3	3.82	5,972	60.88	9,801	13.93
143	56.7	2.04	4.51	73.61	2.15	17.69	12,557	35.96	12.7	7.75	7,069	79.55	8,886	26.20
144	45.9	0.86	4.61	70.64	1.22	22.67	12,101	38.92	31.7	5.39	6,739	61.91	10,885	11.66

Ohio

145	45.5	4.58	5.47	80.46	1.39	8.10	14,888	4.14	2.6	9.38	12,874	88.02	14,626	1.75
146	37.8	0.63	5.38	80.96	1.45	11.58	14,269	9.72	5.5	4.43	12,247	90.07	14,152	4.69
146	47.7	5.74	5.66	77.78	1.38	9.44	14,332	7.71	4.9	11.95	11,515	85.15	13,523	3.30
147	42.9	3.97	5.45	82.04	1.50	7.04	14,965	3.53	1.4	9.12	13,072	89.48	14,642	2.38
148	42.8	3.66	4.95	81.01	1.37	9.01	14,832	5.59	3.2	8.29	12,773	88.51	14,431	3.83

Oklahoma

148	45.9	5.93	5.18	76.48	1.79	10.62	13,667	8.29	2.7	25.05	9,110	72.25	12,609	7.74
149	21.7	1.15	4.85	89.40	1.75	2.85	15,586	2.37	1.9	8.83	13,840	89.27	15,504	0.53
149	15.7	1.36	4.70	90.23	1.84	1.87	15,728	5.11	4.5	8.03	13,662	87.47	15,619	0.70
150	41.7	2.31	5.50	81.43	1.50	9.26	14,711	7.04	3.3	10.01	12,202	86.69	14,075	4.31
150	35.5	7.36	5.43	81.79	1.71	3.71	15,025	2.09	1.0	20.07	11,695	78.93	14,814	1.38
151	40.8	2.06	5.44	83.06	2.09	7.35	15,061	2.81	1.4	8.75	13,320	89.85	14,825	1.57

Oregon

152	44.0	1.15	5.29	72.20	1.68	19.68	12,769	16.10	8.1	13.17	9,031	78.73	11,471	10.16
152	40.7	5.52	....	.....	....	....	11,493	13.77	7.8	7.46	9,054	84.74	10,684	7.05
152	48.1	1.65	....	.....	....	....	14,618	20.84	11.3	8.37	10,348	80.33	12,882	11.88

TABLE 1—*Continued*

ANALYSES AND HEATING VALUES OF AMERICAN COALS

Page of Bulletin 22.	Volatile Matter, Per Cent of Combustible.	Composition of the Combustible.					B.T.U. per Pound Combustible.	As Received.				Air-dry, Ash-free.		
		S	*H*	*C*	*N*	*O*		*M* Moist.	*L* Loss on Air Drying.	*A* Ash.	B.T.U.	$F = 100 - (A + L)$	$\frac{\text{B.T.U.}}{F} = \text{B.T.U.}$	$\frac{M - L}{F} = M_1$
Pennsylvania														
153	38.3	1.38	5.39	84.57	1.72	6.94	15,345	2.61	1.3	6.17	13,997	92.53	15,127	1.42
155	19.0	1.87	4.81	88.71	1.29	3.32	15,840	2.90	2.0	6.74	14,310	91.26	15,680	0.99
157	24.8	1.81	4.84	86.39	1.46	5.50	15,376	4.25	3.9	7.87	13,513	88.23	15,316	0.40
166	25.0	1.50	5.19	88.14	1.45	3.72	15,660	1.90	1.1	6.20	14,390	92.70	15,523	0.86
168	32.4	1.00	5.04	84.87	1.74	7.35	15,511	5.13	4.2	8.71	13,365	87.09	13,346	1.07
169	19.5	1.73	4.93	89.85	1.50	1.99	15,683	1.65	1.3	8.61	14,076	90.09	15,624	1.50
172	1.3	1.00	1.77	94.39	0.71	2.13	14,882	2.80	1.5	7.83	13,298	90.67	14,666	1.43
172	3.7	0.68	3.09	92.91	0.91	2.41	15,248	3.33	2.6	9.12	13,351	88.28	15,123	0.83
175	17.3	1.63	4.46	89.60	1.49	2.82	15,847	1.10	0.5	7.41	14,499	92.09	15,744	0.65
180	17.2	5.09	4.48	87.18	1.59	1.66	15,493	1.78	1.1	9.78	13,702	89.12	15,378	0.76
180	10.0	0.74	3.76	92.15	1.18	2.17	15,457	3.38	2.6	11.50	13,156	85.90	15,315	0.91
Rhode Island														
184	6.6	0.05	1.14	93.00	0.22	5.59	13,120	23.68	23.1	30.77	5,976	46.13	12,955	1.26
185	6.3	0.09	0.80	95.62	0.22	3.27	14,002	2.41	2.0	19.06	10,996	78.94	13,930	0.52
South Dakota														
185	40.0	0.68	....	.....	....	....	12,098	30.45	19.7	12.15	6,944	68.15	10,189	15.77

Tennessee

186	38.4	1.17	5.59	83.44	1.86	7.94	14,960	6.39	4.7	9.53	12,578	85.77	14,665	1.97
187	33.8	0.95	5.40	85.75	1.20	6.70	15,320	3.89	2.9	14.43	12,514	82.67	15,137	1.08
189	39.8	5.73	5.23	82.41	1.49	5.14	15,125	3.12	2.0	14.12	12,517	83.88	14,921	1.32

Texas

189	59.6	1.46	5.67	72.55	1.33	18.99	13,043	34.70	24.6	11.20	7,056	64.20	10,991	15.73
189	70.9	1.00	....	.....	....	....	12,811	33.50	16.3	10.75	7,142	72.95	9,790	23.58
189	45.3	1.61	5.04	73.21	1.48	18.66	12,890	31.06	23.5	7.88	7,870	68.62	11,469	11.02
190	49.6	0.90	5.17	72.06	1.33	20.54	12,452	33.71	25.8	7.28	7,348	66.92	10,980	11.82

Utah

191	45.6	0.60	5.44	79.41	1.25	13.30	14,245	5.58	1.1	8.99	12,170	89.91	13,536	4.98
191	47.2	0.62	5.71	81.19	1.55	10.93	14,764	6.05	3.8	4.87	13,151	91.33	14,399	2.47
192	38.4	0.56	4.66	75.14	1.51	18.13	13,118	9.01	4.1	8.18	10,863	87.72	12,384	5.60
193	45.4	7.27	4.97	76.52	1.19	10.05	13,586	10.35	1.8	9.62	10,874	88.58	12,276	9.65
193	44.0	7.10	4.77	72.83	1.12	14.18	13,081	14.19	2.8	9.92	9,927	87.28	11,374	11.47
194	67.6	2.32	7.73	74.75	1.52	13.68	14,918	7.35	1.1	23.24	10,355	75.66	13,686	8.26
194	46.6	4.88	5.08	66.68	1.22	22.14	11,264	16.59	3.9	13.44	7,882	82.66	9,535	15.35

Virginia

196	38.3	1.32	5.34	83.97	1.36	8.01	15,156	4.06	2.4	4.73	13,826	92.87	14,887	1.79
197	40.2	0.85	5.25	80.32	1.40	12.18	14,918	4.44	2.1	5.98	13,363	92.92	14,381	2.52
197	13.1	0.82	4.38	89.76	0.86	4.18	15,500	4.80	4.1	18.03	11,961	77.87	15,360	0.90
199	19.0	0.68	4.70	90.08	1.12	3.42	15,840	4.00	3.5	4.31	14,520	92.19	15,750	0.54
200	17.5	0.68	4.86	90.93	1.30	2.23	15,910	4.10	3.5	3.18	14,740	93.32	15,795	0.64
201	35.3	0.97	5.58	86.10	1.70	5.65	15,291	3.31	1.9	3.76	14,209	94.34	15,069	1.49

TABLE 1—*Continued*

ANALYSES AND HEATING VALUES OF AMERICAN COALS

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Washington														
202	41.8	0.57	5.66	79.85	1.54	12.38	14,348	6.02	3.5	19.35	10,708	77.15	13,879	3.26
203	47.5	0.44	5.68	75.00	1.77	17.11	13,423	12.05	6.6	10.41	10,414	82.99	12,548	6.56
210	44.0	0.72	5.23	79.40	0.72	13.93	14,796	2.32	1.0	13.58	12,443	85.42	14,569	1.55
214	54.6	0.53	5.25	70.87	1.29	22.06	12,226	27.17	14.3	10.92	7,569	74.78	10,122	17.21
216	8.5	0.72	3.67	91.41	1.53	2.67	15,410	2.70	2.0	10.67	13,350	87.33	15,287	0.80
220	16.3	0.48	4.48	88.91	2.16	3.97	15,264	5.81	4.5	17.04	11,776	78.46	15,013	1.67
West Virginia														
223	47.4	0.92	7.13	85.01	1.60	5.34	16,176	1.80	1.0	3.44	15,330	95.56	16,042	0.84
233	25.3	0.86	5.09	88.33	1.59	4.13	15,399	3.71	2.6	3.39	14,306	94.01	15,218	1.18
235	23.3	0.61	5.19	91.06	1.46	1.68	15,736	5.70	4.9	6.51	13,817	88.59	15,597	0.90
241	21.8	1.27	4.56	87.54	1.11	5.52	15,781	3.94	3.2	4.93	14,382	91.87	15,655	0.81
246	44.3	3.86	5.44	82.13	1.51	7.06	15,291	1.95	0.5	7.86	13,790	91.64	15,048	1.58
247	40.0	0.72	5.30	82.30	1.58	10.10	15,107	4.21	2.3	7.22	13,379	90.48	14,787	2.11
275	19.9	0.60	4.76	90.71	1.13	2.80	16,038	1.75	1.1	4.58	15,023	94.32	15,928	0.69
278	16.5	0.79	4.73	88.71	1.21	4.56	15,820	4.40	3.8	4.10	14,470	92.10	15,711	0.65
281	36.4	0.73	5.14	85.84	1.57	6.72	15,448	2.86	1.6	5.83	14,105	92.57	15,237	1.36
292	18.1	0.86	4.79	90.72	1.66	1.97	15,919	4.26	3.6	6.04	14,279	90.36	15,802	0.73

297	27.8	1.09	1.98	85.02	0.97	10.94	12,956	10.26	1.7	9.83	10,354	89.47	11,573	9.56
302	44.3	0.36	4.46	69.17	1.66	24.35	11,722	18.41	10.0	3.71	9,130	86.29	10,581	9.75
303	39.3	0.17	4.67	72.80	0.41	21.95	12,683	17.24	5.6	1.60	10,294	92.80	11,093	12.54
307	59.9	1.18	3.94	70.19	1.28	23.41	11,194	19.17	5.3	37.12	4,892	57.58	8,496	24.09
309	47.5	4.04	4.85	72.51	1.54	17.06	12,447	22.35	7.0	11.54	8,230	81.46	10,103	18.84
311	43.5	0.72	4.00	68.32	1.42	25.54	11,030	23.30	17.3	3.27	8,100	79.43	10,198	7.55
316	50.6	2.17	3.32	63.30	1.35	29.86	9,630	31.37	14.2	10.12	5,634	75.68	7,458	22.69
317	39.3	0.99	5.09	81.14	1.38	11.40	14,848	5.49	3.5	3.12	13,570	93.38	14,532	2.13
318	39.6	0.84	5.18	83.29	1.44	9.25	14,792	3.96	1.4	4.77	13,502	93.83	14,391	2.73
320	49.4	0.77	3.67	61.35	1.07	33.14	10,141	32.18	21.3	5.41	6,329	73.29	8,636	14.85

TABLE 2

CLASSIFIED LIST OF AMERICAN COALS

	Combustible.				Air-dry, Ash-free.	
	Vol.	S.	O.	B.T.U.	Moist.	B.T.U.
I. Anthracite						
Alaska 4	8.8	0.73	4.04	15,203	1.55	14,968
Colo 5	3.6	0.87	1.32	15,413	1.08	15,247
Pa. 7	1.3	1.00	2.13	14,882	1.43	14,666
Pa. 8	3.7	0.68	2.41	15,248	0.83	15,123
Wash 5	8.5	0.72	2.67	15,410	0.80	15,367
II. Semi-anthracite						
Ark. 1	14.8	2.33	2.57	15,496	1.45	15,272
Pa 11	10.0	0.74	2.17	15,457	0.91	15,398
Va. 3	13.1	0.82	4.18	15,500	0.90	15,439
III. Semi-bituminous						
Ala 1	28.8	0.59	4.45	15,757	1.15	15,577
Ala 2	27.9	1.58	3.42	15,620	0.94	15,475
Alaska 3	15.5	1.29	3.02	15,651	0.60	15,559
Ark. 2	16.7	3.16	1.69	15,624	0.86	15,525
Ark. 5	17.0	3.57	1.25	15,530	0.92	15,387
Ark. 6	20.7	1.47	4.27	15,602	1.34	15,393
Colo 7	23.8	0.58	4.34	15,849	0.83	15,716
Colo 8	25.8	0.72	2.29	15,939	1.43	15,712
Ga 1	19.4	1.55	5.96	15,653	0.74	15,540
Md. 1	16.5	1.13	2.81	15,710	0.90	15,577
Md. 2	16.0	1.02	2.54	15,640	1.10	15,478
Md. 3	19.7	0.94	3.01	15,826	0.80	15,699
Md. 4	17.5	0.98	2.47	15,856	0.66	15,746
Mont 9	18.3	0.96	2.93	15,721	0.61	15,625
Okla. 2	21.7	1.15	2.87	15,586	0.53	15,504
Okla. 3	15.7	1.36	1.87	15,728	0.70	15,619
Pa. 2	19.0	1.87	3.32	15,840	0.99	15,680
Pa. 3	24.8	1.81	5.50	15,376	0.40	15,316
Pa. 4	25.0	1.50	3.72	15,660	0.86	15,523
Pa. 6	19.5	1.73	1.99	15,683	1.50	15,624
Pa. 9	17.3	1.63	2.82	15,847	0.65	15,744
Pa. 10	17.2	5.09	1.66	15,493	0.76	15,378
Va. 4	19.0	0.68	3.42	15,840	0.54	15,750
Va. 5	17.5	0.68	2.23	15,910	0.64	15,795
Wash 6	16.3	0.48	3.97	15,264	1.67	15,013
W. Va. 2	25.3	0.86	4.13	15,399	1.18	15,218
W. Va 3	23.3	0.61	1.68	15,736	0.90	15,597
W. Va 4	21.8	1.27	5.52	15,781	0.81	15,655
W. Va 7	19.9	0.60	2.80	16,038	0.69	15,998
W. Va 8	16.5	0.79	4.56	15,820	0.65	15,804
W. Va 10	18.1	0.86	1.97	15,919	0.73	15,802
IV. Cannel *						
Ky 2	55.5	1.38	7.57	15,800	0.92	15,646
Ky 3	57.0	1.15	7.61	16,013	1.44	15,784
W. Va 1	47.4	0.92	5.34	16,176	0.84	16,042
Utah 6	67.6	2.32	13.68	14,918	8.26	13,686
V. Bituminous, High-grade						
Ala 3	33.4	1.13	6.99	15,590	1.23	15,400
Ala 4	35.3	1.07	7.00	15,214	1.77	14,947
Colo 4	31.3	0.72	9.38	14,681	1.01	14,533
Colo 6	33.7	0.56	8.77	15,559	0.87	15,423
Ill 6	40.0	2.82	9.74	14,818	2.34	14,470
Kan 2	39.8	6.68	5.26	15,167	2.86	14,734
Kan 4	39.5	4.93	7.27	14,809	2.49	14,436
Ky 4	35.3	0.58	8.05	15,328	1.64	15,095

* H in combustible: Ky. 2, 7.13; Ky. 3, 7.46; W. Va. 1, 7.13; Utah, 6, 7.73. The highest H in the other coals is 5.78, Mo. 6. The figures in the first column are the order of the coals of the several States in Table 1.

TABLE 2—*Continued*

	Combustible.				Air-dry, Ash-free.	
	Vol.	S.	O.	B.T.U.	Moist.	B.T.U.
V. Bituminous, High-grade—*Continued*						
N. Mex. 1	41.5	0.74	8.79	14,875	1.64	14,630
N. Mex. 2	34.4	0.96	6.93	15,221	0.80	15,099
Ohio. 1	45.5	4.58	8.10	14,888	1.75	14,626
Ohio. 4	42.9	3.97	7.04	14,965	2.38	14,642
Ohio. 5	42.8	3.66	9.01	14,832	3.83	14,431
Okla. 5	35.5	7.36	3.71	15,025	1.38	14,814
Okla. 6	40.8	2.06	7.35	15,061	1.57	14,825
Pa. 1	38.3	1.38	6.94	15,345	1.42	15,127
Pa. 5	32.4	1.00	7.35	15,511	1.07	15,346
Tenn. 1	38.4	1.17	7.94	14,960	1.97	14,665
Tenn. 2	33.8	0.95	6.70	15,320	1.08	15,137
Tenn. 3	39.8	5.73	5.14	15,125	1.32	14,921
Va. 1	38.3	1.32	8.01	15,156	1.79	14,887
Va. 2	40.2	0.85	12.18	14,918	2.52	14,381
Va. 6	35.3	0.97	5.65	15,291	1.49	15,069
Wash. 3	44.0	5.23	13.93	14,796	1.55	14,569
W.Va. 5	44.3	3.86	7.06	15,291	1.58	15,048
W. Va. 6	40.0	0.72	10.10	15,107	2.11	14,787
W. Va. 9	36.4	0.73	5.14	15,448	1.36	15,237
Wyo. 8	39.3	0.99	11.40	14,848	2.13	14,552
VI. Bituminous, Medium Grade						
Ala. 5	37.7	1.37	10.45	14,467	2.69	14,078
Alaska. 1	44.2	1.83	14.11	13,838	2.55	13,484
Cal. 2	53.8	4.80	11.47	14,336	5.19	13,593
Ill. 2	41.4	1.36	12.02	14,492	5.15	13,745
Ill. 3	37.4	1.14	8.46	14,621	6.02	13,742
Ill. 7	39.3	3.10	9.03	14,724	3.71	14,177
Ind. 1	40.9	2.88	9.50	14,492	5.48	13,698
Ind. 3	47.3	6.60	9.96	14,305	5.01	13,576
Ia. 2	51.2	8.53	8.96	14,206	5.35	13,445
Ia. 3	40.6	6.64	8.03	14,555	6.24	13,647
Kan. 1	44.2	9.94	5.64	14,724	4.09	14,121
Kan. 3	39.8	5.22	5.98	14,922	4.30	14,269
Ky. 1	44.0	4.29	8.90	14,657	6.52	13,702
Ky. 5	43.5	5.64	7.46	14,836	2.98	14,394
Mich. 1	38.8	1.53	9.54	14,499	4.70	13,818
Mich. 2	37.1	1.11	10.51	14,603	5.59	13,786
Mo. 1	44.8	5.16	9.53	14,351	4.65	13,682
Mo. 3	44.6	4.96	11.83	13,892	3.42	13,416
Mo. 4	50.8	6.33	7.73	14,679	3.69	14,136
Mo. 5	45.3	9.45	6.28	14,476	2.83	13,921
Mo. 6	50.2	6.21	6.12	15,134	5.68	14,276
Mont. 5	34.3	4.86	9.50	14,134	2.42	13,791
Mont. 8	39.6	0.60	9.77	14,681	2.30	14,342
N. Mex. 3	44.3	0.68	12.70	14,539	3.06	14,093
Ohio. 2	37.8	0.63	11.58	14,269	4.69	14,152
Ohio. 3	47.7	5.74	9.44	14,332	3.30	13,523
Okla. 4	41.7	2.31	9.26	14,711	4.31	14,075
Utah. 1	45.6	0.60	13.30	14,245	4.98	13,536
Utah. 2	47.2	0.62	10.93	14,764	2.47	14,399
Wash. 1	41.8	0.57	12.38	14,348	3.26	13,879
Wyo. 9	39.6	0.84	9.25	14,793	2.73	14,391
VII. Bituminous, Low Grade						
Alaska. 2	40.8	0.94	18.83	12,964	5.42	12,261
Ill. 1	46.0	6.33	10.53	14,263	6.75	13,300
Ill. 4	40.8	5.55	12.02	13,921	6.02	13,084
Ill. 5	46.2	6.02	10.09	14,155	10.59	12,657
Ind. 2	42.2	1.78	10.55	14,746	9.60	13,329
Ind. 4	44.8	6.73	9.69	14,089	6.17	13,220
Ia. 1	47.5	5.69	9.73	14,305	11.33	12,684
Mo. 2	47.3	4.85	10.68	14,202	7.37	13,156
Mont. 1	33.3	12.99	6.82	13,693	2.37	13,368

TABLE 2—*Continued*

		Combustible.				Air-dry, Ash-free.	
		Vol.	S.	O.	B.T.U.	Moist.	B.T.U.
VII. Bituminous, Low Grade—*Continued*							
Mont.	2	44.4	1.72	20.44	13,338	8.75	12,170*
Mont.	3	43.7	2.00	15.87	13,162	6.34	12,324*
Mont.	4	37.5	0.86	16.21	13,865	7.58	12,813
Mont.	6	32.6	2.88	16.14	12,438	8.09	11,432
N. Mex.	4	42.8	0.78	14.00	13,939	11.70	12,309†
N. Mex.	5	46.8	2.38	15.69	13,322	8.87	12,008†
Okla.	1	45.9	5.93	10.62	13,667	7.74	12,609
Ore.	3	48.1	1.65	....	14,618	11.88	12,882
Utah.	3	38.4	0.56	18.13	13,118	5.60	12,384
Utah.	4	45.4	7.27	10.05	13,586	9.65	12,276
Utah.	5	44.0	7.10	14.18	13,081	11.47	11,374
Wash.	2	47.5	0.44	17.11	13,423	6.56	12,548
VIII. Sub-bituminous and Lignite							
Ark.	3	52.1	0.96	21.17	12,497	22.00	9,750
Cal.	1	53.5	4.62	16.79	12,890	10.95	11,478
Colo.	1	41.4	0.44	16.97	11,619	8.21	10,664
Colo.	2	45.5	0.51	16.52	13,239	15.35	10,094
Colo.	3	41.1	0.39	18.00	12,746	8.68	11,638
Mont.	7	69.0	1.86	23.47	11,900	15.55	10,143
Mont.	10	54.1	0.67	26.64	10,211	25.02	7,656
N. Dak.	1	49.8	1.16	....	11,398	13.93	9,801
N. Dak.	2	56.7	2.04	17.69	12,557	26.20	8,886
N. Dak.	3	45.9	0.86	22.67	12,101	11.66	10,885
Ore.	1	44.0	1.15	19.68	12,769	10.16	11,471
Ore.	2	47.0	5.52	....	11,493	7.05	10,684
S. Dak.	1	40.0	0.68	....	12,098	15.77	10,189
Tex.	1	59.6	1.46	18.99	13,043	15.73	11,077
Tex.	2	70.9	1.00	....	10,811	23.58	10,169
Tex.	3	45.3	1.61	18.66	12,890	11.02	11,578
Tex.	4	49.6	0.90	20.54	12,452	11.82	11,036
Utah.	7	46.6	4.88	22.14	11,264	15.35	9,535
Wash.	4	54.6	0.53	22.06	12,226	17.21	10,122
Wyo.	1	27.8	1.09	10.94	12,956	9.56	11,573
Wyo.	2	44.3	0.36	24.35	11,722	9.75	10,581
Wyo.	3	39.3	0.17	21.95	12,683	12.54	11,093
Wyo.	4	59.9	1.18	23.41	11,194	24.09	8,496
Wyo.	5	47.5	4.04	17.06	12,447	18.84	10,103
Wyo.	6	43.5	0.72	25.54	11,030	7.55	10,198
Wyo.	7	50.6	2.17	29.86	9,630	22.69	7,458
Wyo.	10	49.4	0.77	33.14	10,141	14.85	8,666
Not Classified							
R. I.	1	6.6	0.05	5.59	13,120	1.26	12,955
R. I.	2	6.3	0.09	3.27	14,002	0.52	13,930
Alaska	5	21.7	10.76	5.28	13,945	4.77	13,279
Ark.	4	21.0	1.43	6.44	14,945	1.77	14,722
Idaho.	1	50.9	4.77	....	16,457	16.42	13,757

* Montana 2 and 3 are classed as sub-bituminous by the Bureau of Mines.

† New Mexico 4 and 5 are classed as sub-bituminous by the Bureau of Mines.

Wyoming 6, Sample taken 10 ft. from entrance, coal very much weathered; Wyoming 7, Surface exposure; Wyoming 10, Shallow prospect pit; coal badly weathered.

The Rhode Island coals are graphitic and are not used as fuel. Alaska 5 and Arkansas 4 may be classed as semi-bituminous by their percentage of volatile matter, but they are higher in oxygen and in moisture, and lower in heating value than other semi-bituminous coals. The Idaho coal is apparently a cannel coal very high in moisture, but the ultimate analysis is lacking.

Differences between Actual and Calculated Heating Values.—The following table shows the range of variation of heating value as determined by calorimeter from that found by estimation from the Dulong formula, the Mahler curve and the moisture formula.

RANGE OF VARIATION OF HEATING VALUES

Class.	B.T.U. Greater (+) or Less (−) than Estimated by		
	Dulong Formula.	Mahler Curve.	Moisture Formula.
I. Anthracite	− 164 to + 127	− 76 to +373	− 385 to + 87
II. Semi-anthracite	− 21 to − 193	− 23 to −176	− 233 to −274
III. Semi-bituminous	− 674 to + 546	− 516 to +208	− 557 to +643
IV. Cannel	− 284 to + 172	.....	+ 198 to +686
V. Bituminous, high grade	− 344 to + 842	− 849 to +725	− 447 to +908
VI. Bituminous, medium grade	− 673 to + 592	−1226 to +736	− 923 to +967
VII. Bituminous, low grade	− 309 to +1293	.....	−1674 to +680
VIII. Sub-bituminous and lignite	−1397 to +1292	.....	.....

For the first five classes the maximum variation of the calorimetric from the estimated value by the Dulong formula is 842 B.T.U., by the Mahler curve 849, and by the moisture formula 908 The revised classification is as follows:

CLASSIFICATION OF COALS

	Volatile Matter, Per Cent of Combustible.	Oxygen in Combustible, Per Cent.	Moisture in Air-dry Coal, Free from Ash, Per Cent.	B.T.U. per Pound Combustible.	B.T.U. per Pound Coal, Air-dry, Ash-free.
I. Anthracite	less than 10	1– 4	less than 1.8	14,800–15,400	14,600–15,400
II. Semi-anthracite	10–15	1– 5	less than 1.8	15,400–15,500	15,200–15,500
III. Semi-bituminous	15–30	1– 6	less than 1.8	15,400–16,050	15,300–16,000
IV. Cannel *	45–60	5– 8	less than 1.8	15,700–16,200	15,500–16,050
V. Bituminous, high grade	30–45	5–14	1 –4	14,800–15,600	14,350–15,400
VI. Bituminous, medium grade	32–50	6–14	2.5–6.5	13,800–15,100	11,300–14,400
VII. Bituminous, low grade	32–50	7–14	5 –12	12,400–14,600	11,300–13,400
VIII. Sub-bituminous and lignite	27–60	10–33	7 –26	9,600–13,250	7,400–11,650

* Eastern Cannel. The Utah cannel is much lower in heating value.

Heating Value of Foreign Coals.—The tables on the following pages are abridged from those in the second edition of this work. Those tests of whose reliability there was the slightest doubt have been eliminated from the tables. In the tables of French coals Mahler's tests have been substituted for the now more or less discredited Scheurer-Kestner tests.

HEATING VALUE OF FOREIGN COALS

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
AFRICA												
Songwe River, Nyassa	57.63	26.80	....	....	....	....	0.10	....	15.57	5520	9,936	W. R. Dunstan
Songwe River, Nyassa	47.46	44.54	....	....	....	....	0.52	....	8.40	6050	10,890	W. R. Dunstan
AUSTRALIA												
Unknown (anthracite)	....	....	69.81	8.43	4.35	0.81	0.54	0.29	15.77	9406	16,931	Bunte
Latrobe Valley, Victoria	40.18	34.66	66.07	5.01	24.00	1.30	0.17	22.08	3.45	6341	11,415	James Stirling
Newport, Victoria	....	....	59.27	5.44	25.05	0.24	2.22	....	7.78	5585	10,053	James Stirling
Newport, Victoria	....	....	65.82	6.48	22.30	0.19	2.01	....	3.20	6589	11,860	James Stirling
Boghead	....	....	83.17	10.04	6.79			....	....	9134	16,441	Bunte
AUSTRIA-HUNGARY												
Dombrau, Austria	....	....	81.27	4.60	13.51	0.97	0.55	....	....	7921	14,258	Schwackhöfer
Erzherzog Albrecht, Austria	....	....	82.75	4.69	11.40	0.37	0.79	....	....	8406	15,131	Schwackhöfer
Karwinerer-Larisch, Austria	....	....	83.00	4.70	11.43	0.34	0.50	....	....	8309	14,956	Schwackhöfer
Rossitz, Austria	....	....	82.47	4.68	12.10	0.18	0.57	....	....	7781	14,006	Schwackhöfer
Pilsen Priesen Kamotauer, Aus.	....	....	72.25	5.30	21.62	0.31	0.52	....	....	6978	12,560	Schwackhöfer
Wilozek, Austria	....	....	82.50	4.82	12.03	0.23	0.42	....	....	8344	15,054	Schwackhöfer
Fünfkirchen, Hungary (av. of 4)	....	....	78.83	3.85	5.10	1.70	....	1.10	....	7373	13,271	B. and H. Zeitung
Szabolcs, Hungary (av. of 4)	....	....	79.98	4.10	4.75	1.42	....	1.33	....	7517	13,530	B. and H. Zeitung
Vasos, Hungary (average of 3)	....	....	76.14	4.09	6.54	1.29	....	1.45	....	7162	12,892	B. and H. Zeitung
Carpano, Istria	....	....	60.94	4.08	17.54	1.28	8.72	2.01	14.15	6785	12,213	Welthofer
Senge, Servia	46.88	36.15	58.12	3.78	20.73		....	13.32	4.05	7285	13,113	Welthofer
Senge, Servia	47.00	36.72	57.31	3.54	21.17		....	13.63	2.65	7054	12,697	Welthofer
Senge, Servia	....	....	59.85	4.44	19.41		....	12.63	3.67	7425	13,365	Welthofer
Senge, Servia	51.70	34.64	60.85	4.02	21.47		....	12.43	1.23	6903	12,425	Welthofer

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
CHILI												
Cerro Verde, South Basin	47.40	41.35	....	....	0.60	....	....	11.25	4.75	7520	13,536	Bobinski
Schwager	57.85	40.40	....	....	0.70	....	....	1.75	14.00	7891	14,204	Bobinski
Ccronel	61.40	39.25	....	....	0.85	....	....	6.25	7.00	6641	14,954	Bobinski
Lota	62.30	40.00	....	....	0.93	....	....	7.00	10.40	7390	13,302	Bobinski
Arauco	60.71	39.00	....	....	2.24	....	....	4.50	4.58	6532	11,758	Bobinski
Lebu	59.57	42.00	....	....	0.83	....	....	7.50	8.67	7275	13,095	Bobinski
Valdivia	56.14	45.00	....	....	0.58	....	....	8.25	9.15	7022	12,640	Bobinski
Martha, Magellan	47.25	37.35	....	....	0.48	....	....	14.50	15.40	6983	12,369	Bobinski
Madeleine	40.10	44.20	....	....	0.20	....	....	15.70	9.15	7971	14,348	Bobinski
Punta Arefias	40.10	42.15	....	....	0.47	....	....	17.75	9.50	7917	14,250	Bobinski

FRANCE (P. MAHLER)

Kind of Coal.	Coal Dry and Free from Ash.						
		Composition.			Heating Value, Calories.		
	Per Cent Fixed Carbon.	C.	H.	O+N.	Actual.	By Dulong's * Formula.	Difference.
Anthracite and Anthracitic							
De la Mure (Grande Couche)	97.25	95.24	1.50	3.26	8216	8173	− 43
Hay-Duong (Tonkin)	96.83	92.86	2.16	4.99	8121	8130	+ 9
Kebao	94.80	93.46	3.07	3.48	8532	8528	− 4
Commentry	96.81	91.49	3.12	5.39	8456	8333	−123
Blanzy, Puits Ste.-Barbe	94.00	90.00	3.17	6.83	8203	8169	− 34
Grande-Combe, Puits Petassas	93.29	91.46	3.95	4.59	8540	8653	+113
Creusot	89.56	92.39	3.78	3.83	8687	8704	+ 17
Average	.....	.....	.....	.....	.....	.....	+ 18
Fat and Semi-fat (Demi-grasse)							
Demi-grasse, d'Anzin, Fosse St. Marc	85.92	91.26	4.27	4.48	8656	8751	+ 95
Demi-grasse, Grande Combe	86.62	91.19	4.46	4.35	8756	8817	+ 61
Demi-grasse, Roche-la-Molière	86.00	90.11	4.38	5.51	8767	8651	−116
Demi-grasse, Aniche	88.07	90.10	4.40	5.49	8834	8659	−175
Grasse, Anzin, great vein	78.49	89.20	4.67	6.14	8574	8651	+ 77
Grasse, Ronchamp	76.77	88.89	4.84	6.27	8797	8678	−119
Grasse, Lens	80.50	90.03	4.80	5.17	8839	8805	− 34
Grasse, Carmaux	78.25	87.84	4.87	7.30	8639	8559	− 80
Grasse, Roche-la-Molière	77.15	89.53	4.84	5.63	8867	8757	−110
Grasse, Saint Etienne	79.16	89.23	5.03	5.74	8857	8796	− 61
Grasse, Mines de Portes (Gard)	80.71	86.52	4.84	8.64	8667	8382	−285
Average	.....	.....	.....	.....	.....	.....	− 66
Fat Gas-coals							
Bethune	69.59	87.03	5.37	7.60	8668	8654	− 14
Lens	69.20	87.26	5.44	7.30	8749	8705	− 44
Firminy	67.98	85.39	5.58	9.13	8573	8524	− 49
Montrambert	65.73	84.52	5.54	9.94	8598	8407	−191
Commentry	60.04	85.66	5.60	8.73	8408	8573	+165
Cannel-coal, Niddrie	47.00	83.79	6.57	9.63	8431	8717	+286
Average	.....	.....	.....	.....	.....	.....	+ 52
Flaming Coals, Lignitic							
Montoic	62.93	83.95	5.64	10.42	8570	8371	−199
Blanzy (Puits Ste.-Marie)	68.05	84.26	5.27	10.46	8350	8271	− 79
Decazeville (Bourran)	64.20	83.17	5.68	11.14	8270	8294	+ 24
Blanzy (Puits Ste.-Eugénie)	60.61	81.54	5.64	12.83	8083	8072	− 11
Decazeville (Tramont)	58.77	78.72	5.67	15.61	7837	7735	−102
Average	.....	.....	.....	.....	.....	.....	− 74
Average of above four classes	.....	.....	.....	.....	.....	.....	− 18
Lignites.							
Terre de Feu	47.23	71.01	5.94	23.05	7039	6882	−157
Trifail (Styria)	49.66	69.24	5.06	25.71	6616	6317	−299
Vaurigard	50.05	66.36	5.01	28.63	6076	5938	−138
Wood							
Partially dry, Sapin de Norvège	.....	51.08	6.02	42.90	4828	4428	−400
Bois de Chêne de Lorraine	.....	50.44	5.88	43.69	4689	4293	−396
Cellulose, $C_{12}H_{10}O_{10}$	.....	44.44	6.17	49.39	4200	3617	−583

* Dulong's formula, slightly modified by Mahler is:

$$Q = \frac{1}{100}\left[8140C + 34{,}500\left(H - \frac{(O+N)-1}{8}\right)\right].$$

It may be put under the form $Q = {}^1/_{100}[8140C + 34{,}500H - 4312(O+N-1)]$.
Mahler's own formula is $Q = {}^1/_{100}[8140C + 34{,}500H - 3000(O+N)]$.

GERMANY

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Name.	Composition of Air-dry Coal.						Combustible.
	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Sulphur.	Water.	Ash.	
A. Ruhrcoal							
1. Altenessen	76.30	4.65	6.52	1.07	1.75	9.71	88.54
2. Bonifacius	79.60	4.23	6.77	1.71	1.09	6.60	92.31
3. Concordia	84.16	5.03	7.78	0.86	1.32	0.85	97.83
4. Consolidation	81.82	4.85	6.12	0.96	1.14	5.11	93.75
5. Dahlhausen-Tiefbau	83.24	4.05	3.13	1.26	1.06	7.26	91.68
6. Dannenbaum	85.18	4.38	4.39	1.06	1.84	3.15	95.01
7. Dannenbaum	83.55	4.54	4.93	1.02	0.80	5.16	94.04
8. Ewald	79.27	5.13	10.36	0.63	2.18	2.43	95.39
9. Friedrich Ernestine	80.59	4.94	6.85	1.12	1.54	4.96	93.50
10. Fröhliche Morgensonne	89.27	4.41	2.74	1.25	0.70	1.63	97.67
11. General	81.96	4.81	6.62	1.57	1.42	3.62	94.96
12. Graf Beust	79.05	4.93	10.52	1.62	0.59	3.29	96.12
13. Hansa	79.52	5.23	9.83		2.08	3.34	94.58
14. Holland	83.37	4.77	5.00	1.01	0.99	4.86	94.15
15. Hörde	80.08	3.68	4.11	1.49	0.80	9.84	89.36
16. Hugo	80.67	5.42	9.11		1.70	3.10	95.20
17. Lothringen	82.63	4.55	6.22	1.02	1.49	4.09	94.42
18. Mont-Cenis	66.20	4.30	7.43	1.70	2.50	17.87	79.63
19. Pluto	80.97	5.05	9.27	0.41	1.52	2.78	95.70
20. Recklinghausen	81.22	5.11	6.32	1.43	1.44	4.48	94.08
21. Mathias Stinnes	81.65	4.49	4.02	1.53	1.28	7.03	91.69
22. Shamrock II	82.36	4.79	3.63	1.19	1.10	6.93	91.97
23. Shamrock	83.56	4.77	5.11	1.28	1.05	4.23	94.72
24. Unser Fritz	80.48	5.22	8.30		1.88	4.12	94.00
25. Viktoria Mathias	80.72	4.80	8.66	1.56	0.98	0.08	95.74
26. Grube Vollmond	79.76	4.77	5.44	1.30	0.92	7.81	91.27
27. Westende	81.36	4.76	3.33	1.53	1.18	7.84	90.98
28. Wilhelmine Viktoria	79.82	5.17	8.43		1.85	4.73	93.42
29. Zollverein	71.15	4.65	9.63	1.29	2.99	9.69	87.32
B. Saar Coal							
1. Camphausen Level III	80.35	5.21	7.84	0.86	1.22	4.52	94.26
2. Dudweiler	78.26	5.11	8.57	0.97	1.32	5.77	92.91
3. Frankenholz	77.77	5.18	10.74	0.86	2.30	8.15	94.59
4. Friedrichsthal	76.20	4.98	9.28	1.11	2.03	6.40	91.57
5. Heinitz I	77.29	4.97	8.54	0.72	2.00	6.48	91.52
6. von der Heidt	69.07	4.21	10.93	1.12	3.90	10.77	85.33
7. Itzenplitz	79.15	4.72	6.52	1.40	1.92	6.29	91.79
8. Itzenplitz	72.96	5.35	11.51	1.41	3.68	5.09	91.23
9. König I.	76.69	5.20	8.05	2.10	1.21	6.75	92.04
10. Kohlwald	73.48	5.03	10.86	0.93	4.05	5.65	90.30
11. Kreuzgräben, Level I	80.43	5.24	7.94	0.49	1.45	4.45	94.10
12. Louisenthal	70.33	4.67	11.39	1.05	4.82	7.74	87.46
13. Maybach, Level II	79.67	5.21	8.37	0.70	1.60	4.45	93.95
14. Püttlingen	68.67	4.57	10.80	0.80	3.93	11.23	84.84
15. Reden	72.98	5.06	11.30	0.99	3.45	6.22	90.33
16. St. Ingbert Gas-coal	81.49	4.99	8.31	0.65	1.73	2.83	95.44
17. St. Ingbert Heating-coal	81.26	5.30	7.26	0.95	1.24	3.99	94.77

* Dulong formula for calculating heat-units (Verbandsformel).

—*Continued.*

request of Professor H. BUNTE

Composition of Pure Coal.							Calories of Fuel.		Calories of Combustible.		
Carbon.	Hydrogen.	Oxygen and Nitrogen.	Sulphur.	Coke.	Fixed Carbon.	Volatile Matter.	Dulong.*	Calorimeter.	Dulong.*	Calorimeter.	Number.
86.19	5.24	7.37	1.20	....	....	....	7310	7334	8271	8298	1
86.23	4.59	7.33	1.85	82.27	75.67	16.64	7467	7537	8097	8172	2
86.03	5.14	7.95	0.88	....	....	....	8008	8078	8194	8265	3
87.27	5.17	6.53	1.03	75.15	70.04	23.71	7828	7827	8371	8370	4
90.79	4.42	3.41	1.38	84.78	77.52	14.16	7829	7816	8546	8532	5
89.65	4.62	4.62	1.11	77.12	73.97	21.04	8026	8080	8459	8516	6
88.85	4.83	5.24	1.08	....	....	....	7926	....	8434	....	7
83.10	5.38	10.86	0.66	....	....	....	7549	7522	7928	7899	8
86.19	5.28	7.33	1.20	70.08	65.12	28.38	7731	7736	8278	8283	9
91.40	4.51	2.81	1.28	85.18	83.55	14.12	8438	8441	8644	8646	10
86.31	5.07	6.97	1.65	70.54	66.92	28.04	7824	7840	8248	8265	11
82.24	5.13	10.95	1.68	74.43	71.14	24.98	7488	7486	7794	7792	12
84.08	5.53	10.39		68.30	64.96	29.62	7650	....	8101	....	13
88.55	5.07	5.31	1.07	78.82	73.96	20.19	7973	7900	8475	8398	14
89.62	4.12	4.59	1.67	86.16	76.32	13.04	7435	7482	8326	8379	15
84.81	5.55	9.64		65.70	61.36	32.65	7820	....	8225	....	16
87.52	4.82	6.58	1.08	76.28	72.19	22.23	7804	7840	8275	8313	17
83.14	5.40	9.33	2.13	71.83	53.96	25.67	6368	6424	8016	8086	18
84.60	5.28	9.70	0.42	....	....	....	7688	7662	8043	8016	19
86.33	5.43	6.72	1.52	71.38	66.90	27.18	7859	7871	8363	8376	20
89.05	4.90	4.38	1.67	78.73	71.70	19.99	7800	7842	8513	8560	21
89.55	5.21	3.95	1.29	78.46	71.53	20.44	7953	7978	8655	8682	22
88.22	5.04	5.39	1.35	78.36	74.13	20.59	7992	8015	8444	8468	23
85.62	5.55	8.83		65.90	61.78	32.22	7780	....	8288	....	24
84.31	5.01	9.05	1.63	73.74	70.46	25.28	7620	7637	7965	7983	25
87.39	5.23	5.96	1.42	77.56	69.75	21.52	7674	7679	8415	8420	26
89.43	5.23	3.66	1.68	80.27	72.43	18.55	7881	7907	8670	8699	27
85.44	5.53		9.03	67.40	62.67	30.75	7700	....	8254	....	28
82.17	5.32	11.03	1.48	....	....	....	6825	6899	7837	7922	29
85.24	5.52	8.33	0.91	....	....	....	7749	7518	8224	7983	1
84.23	5.50	9.22	1.05	65.49	59.72	33.19	7527	7538	8110	8122	2
82.25	5.48	11.36	0.91	62.70	59.55	35.00	7420	7509	8286	7957	3
83.21	5.45	10.13	1.21	60.83	54.43	37.14	7296	7343	7862	8032	4
84.45	5.43	9.33	0.79	66.40	59.92	31.60	7397	....	8095	....	5
80.95	4.93	12.81	1.31	61.70	50.93	34.40	6424	6478	7556	7619	6
86.23	5.14	7.10	1.53	74.40	68.11	23.68	7567	7571	8256	8260	7
79.97	5.86	12.62	1.55	59.37	54.28	36.95	7051	7019	7753	7718	8
83.32	5.65	8.75	2.28	61.07	54.32	37.72	7473	7571	8127	8233	9
81.37	5.57	12.03	1.03	60.21	54.56	35.74	7016	6989	7796	7766	10
85.46	5.56	8.46	0.52	....	....	....	7750	7622	8245	8109	11
80.43	5.34	13.03	1.20	....	....	....	6635	6663	7619	7652	12
84.80	5.54	8.92	0.74	....	....	....	7678	7763	8183	8273	13
80.94	5.39	12.73	0.94	64.95	53.72	30.12	6492	6533	7680	7729	14
80.79	5.60	12.51	1.10	62.30	56.08	34.25	6974	6971	7744	7740	15
85.38	5.23	8.71	0.68	68.46	65.63	29.81	7752	7798	8133	8181	16
85.75	5.59	7.66	1.00	68.50	64.51	30.26	7872	7847	8314	8287	17

$$8100C + 29{,}000\left(H - \frac{O}{8}\right) + 2500\,S - 600\,W$$

GERMANY

Name.	Composition of Air-dry Coal.						Combustible.
	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Sulphur.	Water.	Ash.	
C. Upper Silesia Coal							
1. Grube Deutschland	71.90	4.56	17.37	1.15	1.58	3.44	94.98
2. Gottesberger Viktoria (run of mine)	81.12	4.24	4.93	1.23	1.65	6.83	91.52
3. Guidogrube	77.79	4.85	10.07	0.57	1.67	5.05	93.28
4. Grube Königin Louise	70.60	4.30	8.77	1.57	2.28	12.48	85.24
5. Mathildengrube	78.31	4.70	9.87	0.75	2.05	4.32	93.63
6. Paulusgrube	73.96	4.40	15.16	1.41	1.95	3.12	94.93
7. Schacht Vereinigt Feld	70.17	5.17	9.39	1.26	8.14	5.87	85.99
D. Saxon Coal							
1. Kaisergrube Gersdorf b. Oelsnitz	71.45	4.76	10.06	1.30	8.91	3.52	87.57
2. Vereinigt Feld Bokwa-Hohndorf	74.63	4.97	9.60	1.80	3.50	5.50	91.00
3. Zwickau-Oberhohndorf Wilhelmschacht	75.95	5.35	11.17	0.63	3.68	3.22	93.10
E. Upper Bavaria Molasses Coal							
1. Haushamer Large Coal	58.01	4.42	12.02	4.87	7.37	13.31	79.32
2. Miesbacher Coal	51.92	3.75	13.44	5.31	17.12	8.46	74.42
3. Penzberger (run of mine)	47.78	3.83	10.92	5.24	10.18	22.05	67.77
F. Saxon Brown Coal							
1. " Alfred " near Calbe a. S.	41.41	3.29	9.84	2.12	36.26	7.08	56.66
2. " Bach " near Ziebingen	35.93	2.56	13.20	0.99	45.33	1.99	52.68
3. Meuselwitzer Revier " Fortschritt "	44.47	3.67	14.69	1.72	27.13	8.32	64.55
4. Gnadenhütte b. Klein-Mühlingen	37.16	3.39	9.62	1.66	38.68	9.49	51.83
5. " Greppen "	43.37	3.25	17.54	1.93	22.85	11.06	66.09
6. " Lützkendorf "	31.12	2.79	9.42	3.87	47.45	5.35	47.20
7. " Marie Louise "	45.40	3.73	10.72	3.59	29.27	7.29	63.44
G. Peat and Lignite							
1. Peat, " Pschorrschwaige "	38.76	3.66	21.27	0.26	29.14	6.91	63.95
2. Compressed Peat, " Hofmark-Steinfels "	49.31	4.48	24.07	0.39	16.47	5.28	78.25
3. Lignite, Josefszeche in Schwanenkirchen	28.80	2.54	9.55	2.87	40.35	15.89	43.76
4. Peat, " Ostrach "	45.93	4.70	29.18	0.61	14.06	5.52	80.42
H. Coal Briquettes							
1. Dahlhausen Tiefbau	83.24	4.05	3.13	1.26	1.06	7.26	91.68
2. Haniel & Co	81.96	4.15	3.14	0.88	1.77	8.10	90.13
3. Hugo Stinnes, Strassburg	80.85	4.45	4.82	1.19	1.76	6.93	91.31
4. Stachelhaus & Buchloh	82.69	4.10	3.60	1.36	2.10	6.15	91.75
J. Brown-coal Briquettes							
1. Stempel " Fürst Bismarck "	54.35	4.66	15.21	2.28	15.77	7.73	76.50
2. Würfel-Brikett C* Ilse, Bergb.-Act.-Ges. in Gross-Raschen-Senftenberg	55.91	4.07	19.14	0.78	14.77	5.33	79.90
3. Würfel-Brikett S* Rechenberg & Cie., Grube Marienglück	51.74	4.24	18.57	1.00	18.95	5.50	75.55
4. Stempel " Rositz "	51.73	4.32	16.37	1.50	19.40	6.68	73.92
5. Gewerkschaft " Schwarzenfeld "	48.20	4.20	15.84	2.98	10.26	18.52	71.22
6. Stempel " Siegfried "	53.66	4.58	15.59	2.58	13.65	9.94	76.41
7. Zeche " Waldau "	50.97	4.20	15.25	2.52	16.57	10.49	72.94
K. Gas-coke							
1. " Consolidation " (Ruhr)	85.18	0.70	4.04	0.87	1.79	7.42	90.79
2. " Rhein, Elbe und Alma " (Ruhr)	85.30	0.81	4.80	0.88	1.71	6.50	91.79
3. " Ewald " (Ruhr)	80.68	0.90	3.74	1.17	2.33	11.18	86.49
4. " Bonifacius " (Ruhr)	82.03	1.07	3.61	1.02	1.53	10.74	87.73
5. " Camphausen " (Saar)	82.91	1.00	2.60	1.43	1.79	10.27	87.94
6. " Heinitz " (Saar)	88.08	0.78	2.85	0.81	0.96	6.52	92.52
7. " Königin Louise " (Upper Silesia)	86.35	0.54	2.01	0.96	3.73	6.41	89.86

* Dulong formula for calculating heat-units (Verbandsformel):

—*Continued.*

Composition of Pure Coal.							Calories of Fuel.		Calories of Combustible.		
Carbon.	Hydrogen.	Oxygen and Nitrogen.	Sulphur.	Coke.	Fixed Carbon.	Volatile Matter.	Dulong.*	Calorimeter.	Dulong.*	Calorimeter.	Number.
75.70	4.80	18.29	1.21	65.73	62.29	32.69	6536	6881	6891	7254	1
88.64	4.63	5.39	1.34	81.46	74.63	16.89	7643	7646	8362	8365	2
83.29	5.20	10.80	0.61	....	....	....	7346	7429	7895	7983	3
82.83	5.04	10.29	1.84	71.18	58.70	26.54	6671	6662	7847	7837	4
83.64	5.02	10.54	0.80	67.82	63.50	30.13	7355	7414	7868	7931	5
77.91	4.64	15.97	1.48	64.19	61.07	33.86	6739	6804	7112	7180	6
81.60	6.01	10.92	1.47	60.50	54.63	31.36	6825	6801	7994	7966	7
81.59	5.44	11.49	1.48	59.75	56.23	31.34	6782	6750	7805	7769	1
82.00	5.46	10.55	1.99	....	....	....	7162	7169	7893	7901	2
81.58	5.74	12.00	0.68	....	....	....	7292	7299	7856	7864	3
73.14	5.57	15.15	6.14	56.50	43.19	36.13	5623	5623	7144	7144	1
69.77	5.04	18.06	7.13	45.35	36.89	37.53	4836	4851	6512	6532	2
70.50	5.65	16.12	7.73	55.13	33.08	34.69	4655	4710	6959	7040	3
73.08	5.81	17.37	3.74	30.35	23.27	33.39	3787	3741	7068	6987	1
68.20	4.86	25.06	1.88	26.44	24.45	28.23	2927	2913	6072	6046	2
68.89	5.69	22.76	2.66	35.59	27.27	37.28	4014	4059	6471	6541	3
71.70	6.54	18.56	3.20	28.30	18.81	33.02	3454	3426	7112	7058	4
65.62	4.92	26.54	2.92	38.51	27.45	38.64	3722	3870	5854	6063	5
65.93	5.91	19.96	8.20	24.98	19.63	27.57	2800	2818	6536	6574	6
71.57	5.88	16.89	5.66	34.90	27.61	35.83	4285	4319	7032	7085	7
60.61	5.72	33.26	0.41	29.60	22.69	41.26	3261	3283	5383	5407	1
63.02	5.73	30.76	0.49	31.25	25.97	52.28	4331	4364	5661	5704	2
65.81	5.81	21.82	6.56	34.00	18.11	25.65	2552	2578	6385	6421	3
57.11	5.84	36.29	0.76	33.16	27.64	52.78	3956	3993	5024	5070	4
90.79	4.42	3.41	1.38	84.78	77.52	14.16	7829	7816	8546	8532	1
90.94	4.60	3.48	0.98	85.60	77.50	12.63	7734	7804	8593	8671	2
88.55	4.87	5.28	1.30	76.35	69.42	21.89	7685	7616	8429	8353	3
90.13	4.47	3.92	1.48	83.92	77.77	13.98	7778	7822	8491	8539	4
71.05	6.09	19.88	2.98	39.87	32.14	44.36	5165	5098	6876	6787	1
70.00	5.09	23.95	0.98	40.17	34.84	45.06	4947	4899	6303	6243	2
68.49	5.61	24.58	1.32	38.92	33.42	42.13	4659	4583	6318	6217	3
69.98	5.84	22.15	2.03	....	....	....	4770	4788	6610	6634	4
67.68	5.90	22.24	4.18	49.40	30.88	40.34	4561	4523	6491	6438	5
70.23	5.99	20.40	3.38	40.78	30.84	45.57	5092	5188	6784	6910	6
69.88	5.76	20.91	3.45	40.09	29.60	43.34	4756	4725	6659	6616	7
93.82	0.77	4.45	0.96	98.00	90.50	0.21	6967	7057	7686	7785	1
92.93	0.88	5.23	0.96	96.25	89.75	2.04	6982	7071	7617	7716	2
93.28	1.04	4.32	1.36	95.16	93.98	2.51	6675	6716	7734	7781	3
93.50	1.22	4.12	1.16	95.30	84.56	3.17	6841	6851	7808	7819	4
94.28	1.14	2.96	1.62	95.41	85.14	2.80	6935	6936	7899	7900	5
95.20	0.84	3.08	0.88	98.30	91.78	0.74	7271	7268	7865	7862	6
96.09	0.60	2.23	1.08	94.34	87.93	1.93	7080	7111	7903	7938	7

$8100\,C+29{,}000\left(H-\frac{O}{8}\right)+2500\,S-600\,W.$

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
GERMANY												
Guido, Schleswig	....	....	77.79	4.85	10.07		0.57	1.67	5.05	7862	14,052	Bunte
"Plattel Kohle," Bohemia (fines)	....	....	59.96	5.56	7.93	1.00	1.08	3.23	21.24	8142	14,656	"
" " " (lump)	....	....	60.07	5.66	7.76	1.16	1.16	3.04	21.15	8163	14,694	"
" " "	....	....	79.38	7.36	13.26	....	1.43	....	....	8215	14,787	"
Hausham, Bavaria	....	....	57.61	4.43	18.84		....	7.75	11.37	7089	12,760	Stuchlik
Penzberg, Bavaria	....	....	56.70	4.34	19.78		....	11.35	7.83	7124	12,823	"
Miesbach, Bavaria	....	....	49.83	3.93	20.41		....	15.82	10.01	6136	11,045	"
Feld-Bokwa Hohndorf, Saxony	....	....	82.00	...	....	12.54	1.99	....	....	7878	14,180	Bunte
Zwickau, Saxony	....	....	81.58	5.74	....	12.68	0.68	....	....	7840	14,112	"
Königshütte, Prussia	....	....	80.59	4.66	13.57	0.67	0.51	....	....	7926	14,267	Schwackhöfer
Morgenstern, "	....	....	77.27	4.00	17.59	0.49	0.65	....	....	7235	13,023	"
Caroline, Prussia	....	....	77.50	4.07	17.20	0.29	0.93	....	....	7260	13,068	"
Waterloo, Prussia	....	....	79.38	4.26	15.48	0.44	0.44	....	....	7482	13,468	"
Westende, Prussia	....	....	80.03	4.38	14.40	0.47	0.72	....	....	7500	13,518	"
Fanny, Prussia	....	....	77.39	4.45	17.23	0.35	0.58	....	....	7178	12,922	"
Wildensteinsegen, Prussia	....	....	79.57	4.24	15.36	0.28	0.55	....	....	7361	13,250	"
Morgenroth, Prussia	....	....	78.85	4.10	16.17	0.41	0.45	....	....	7282	13,108	"
Georg, Prussia	....	....	78.62	4.18	16.32	0.33	0.55	....	....	7208	12,974	"
Eugénie, Prussia	....	....	79.77	4.63	14.56	0.26	0.78	....	....	7427	13,368	"
Veronika, Prussia	....	....	82.37	4.94	11.90	0.22	0.57	....	....	7778	14,000	"
Chasé, Prussia	....	....	80.58	4.32	13.93	0.40	0.77	....	....	7347	13,224	"
Louisengluck, Prussia	....	....	80.26	4.38	14.07	0.82	0.47	....	....	7155	12,879	Schwackhöfer
Maybach, Saarbruck, "	....	....	84.80	5.54	....	9.66	...	....	....	8263	14,873	Bunte
Kreuzgraben, " "	....	....	84.56	5.56	....	8.98	...	....	....	8099	14,578	"
Camphausen, " "	....	....	85.24	5.52	....	9.24	...	....	....	7975	14,355	"
Von der Heydt, " "	....	....	80.51	5.38	....	14.18	...	....	....	7546	13,583	"
Heinitz, I. " "	....	....	83.20	5.25	....	11.55	...	....	....	8008	14,414	"

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
GERMANY—*Continued*												
Louisenthal, Saarbruck, Prussia.	....	....	80.43	5.34	....	14.23	...	....	....	7620	13,716	Bunte
Altenwald, " " .	63.15	19.59	83.14	4.73	....	12.51	...	....	....	8450	15,210	"
Sulzbach, " " .	66.30	16.75	83.05	4.95	....	12.00	...	....	....	8400	15,120	"
Von der Heydt, " " .	61.00	20.56	81.56	4.98	....	13.46	...	....	....	8220	14,796	"
Friedrichsthal, " " .	58.44	20.53	78.97	4.67	....	16.76	...	....	....	8220	14,796	"
Hermenegilde, Silesia.....	....	....	81.61	4.79	13.17	0.20	0.23	....	....	8034	14,461	Schwackhöfer
Waldenburg Gluckshilf, I.....	....	....	83.47	4.66	10.92	0.22	0.73	....	....	8215	14,788	"
Jaklowitz.....	....	....	83.29	4.26	11.57	0.23	0.45	....	....	8086	14,565	"
Michalowitz.....	....	....	81.96	4.50	12.95	0.30	0.29	....	....	7853	14,136	"
Waldenburg Gluckshilf, II.....	....	....	83.28	4.63	10.83	0.35	0.91	....	....	8017	14,434	"
Neurod Wengelhaus, I.....	....	....	82.23	4.70	11.51	0.38	1.12	....	....	7885	14,193	"
Neurod Wengelhaus, II.....	....	....	79.13	4.40	8.85	0.38	2.30	....	....	7844	14,119	"
Ferdinand.....	....	....	81.40	4.65	14.29	0.32	0.34	....	....	7557	13,603	"
Consolidation.....	....	....	84.29	5.27	9.37		1.07	....	....	8177	14,719	Bunte
Pluto.....	....	....	84.60	5.28	9.70		0.42	....	....	8090	14,562	"
Ewald.....	....	....	83.10	5.38	10.86		0.66	....	....	7957	14,323	"
Harpener.....	....	....	87.73	4.80	6.23		1.24	....	....	8380	15,084	"
General Erbstollen, Ruhr.....	75.78	15.51	....	4.21	5.48	....	...	1.34	7.37	8804	15,847	"
Bonifazius-zeche (locomot. coal)	72.96	21.75	....	4.85	6.46	....	...	1.01	4.28	8411	15,140	"
" " (gas).....	66.80	28.02	....	9.84	3.45	....	...	1.81	3.37	8028	14,471	"
König Grube, Saar.....	56.52	30.67	....	4.67	10.98	....	...	5.09	7.72	7914	14,245	"
" " "	61.08	29.55	....	4.92	9.26	....	...	4.07	5.30	8039	14,421	"
St. Ingebert (1st quality).....	64.05	30.66	....	5.11	8.40	....	...	2.72	2.57	8400	15,120	"
" (2d quality).....	60.86	27.51	....	4.58	7.43	....	...	3.41	8.22	8221	14,798	"
" (3d quality).....	59.76	25.68	....	4.60	7.97	....	...	3.12	11.44	8269	14,883	"
Mittelbexbach (No. 3 seam)....	54.44	33.56	....	4.96	10.16	....	...	3.26	8.74	8083	14,550	"
" (No. 6 seam)....	57.62	32.74	....	5.07	9.92	....	...	2.75	6.89	7995	14,390	"
" (No. 9 seam)....	57.54	30.76	....	4.77	9.63	....	...	2.79	8.91	8164	14,696	"
" (No. 10 seam)...	57.00	29.99	....	4.69	9.91	....	...	2.91	10.10	8224	14,803	"

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
GERMANY—*Continued*												
Heinitz-Dechen	58.28	31.45	....	5.15	8.94	....	...	2.54	7.73	8298	14,937	Bunte
Reden-Merchweiler	60.08	32.20	....	4.98	11.53	....	...	4.80	2.92	7630	13,734	"
Dudweiler	65.47	28.23	....	5.01	7.71	....	...	2.25	4.05	8325	14,986	"
Friedrichsthal	57.01	31.23	....	4.74	10.40	....	...	2.99	8.77	8605	14,375	"
Ziehwald	56.53	33.04	....	4.55	11.15	....	...	5.06	5.37	7511	13,520	"
Louisenthal	58.78	30.20	....	4.42	12.43	....	...	6.97	4.05	7505	13,509	"
Griesborn	50.24	30.31	....	4.08	14.10	....	...	6.21	13.24	7542	13,575	"
Mantau, Bohemia	57.76	27.23	....	4.46	8.86	....	...	8.78	6.23	7819	14,073	"
Fremosna (Stark's)	54.06	27.11	....	4.08	9.97	....	...	12.50	6.33	7468	13,443	"
Turn and Taxis (large)	58.43	29.42	....	4.87	10.33	....	...	7.38	4.77	7777	13,998	"
" " " (average)	57.85	29.89	....	4.93	9.90	....	...	6.59	5.67	7601	13,682	"
Miröschau (large)	53.80	31.01	....	4.58	10.97	....	...	8.84	6.35	7527	13,550	"
" (small)	51.33	31.13	....	4.20	10.99	....	...	9.11	9.43	7455	13,419	"
Zwickau, Saxony	50.91	28.22	....	4.18	10.34	.....	...	11.16	9.71	7997	14,394	"
Louisa pit, Heinitz seam, Silesia	64.30	26.76	....	4.62	8.92	....	...	2.83	6.11	7794	14,030	"
" " Schuckman seam	64.20	27.75	....	4.74	9.82	....	...	3.25	4.80	8296	14,932	"
King's pit, Gerhard seam	61.74	29.17	....	4.68	10.79	....	...	4.08	5.01	7924	14,262	"
" Sattel seam	61.50	27.48	....	4.74	10.54	....	...	3.78	7.24	7914	14,245	"
GREAT BRITAIN												
Bickershaw	63.87	29.90	78.93	4.90	7.24	1.56	1.07	4.36	1.96	7778	14,000	Thwaite
Crombourke	57.87	31.67	69.77	4.82	12.45	1.33	1.45	7.15	3.31	8327	14,989	Thwaite
Derbyshire (average of 8)	56.30	41.00	79.68	4.94	10.28	1.41	1.01	....	2.65	8120	14,616	Anonymous
Lancashire (average of 26)	53.12	42.00	77.90	5.32	9.53	1.30	1.44	....	4.88	8113	14,602	"
Newcastle (average of 18)	57.23	39.00	82.12	5.31	5.69	1.35	1.24	....	3.77	8446	15,203	"
Wales (average of 37)	68.09	27.00	83.78	4.79	4.15	0.98	1.43	....	4.91	8402	15,123	"
Nixon Navigation	84.05	11.72	88.03	4.11	1.98	0.96	0.79	1.62	3.22	8340	15,012	Thwaite

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
GREAT BRITAIN—*Continued*												
Nixon Navigation	87.72		10.32			....	...	....	....	8595	15,471	Mahler
Pemberton	56.46	32.29	72.43	5.16	8.84	1.41	1.02	6.70	4.55	8161	14,690	Thwaite
Pendleton	65.66	28.53	79.76	4.89	7.52	1.43	0.63	3.90	1.91	8213	14,783	"
Thackerley Company	50.28	30.10	68.14	4.78	4.86	1.22	1.62	4.72	14.90	8024	14,433	"
Tyldesley Company	57.76	32.09	74.46	5.10	8.25	1.53	0.65	6.07	4.09	7868	14,162	"
Upper Drumgray Seam	65.04	25.63	75.48	4.98	7.86	1.59	0.75	2.78	6.55	8145	14,661	"
Wigan	64.10	28.31	76.49	4.96	8.46	1.44	1.24	4.64	2.75	8155	14,679	"
CHINA												
Anthracite, Tonkin	....	....	92.45	3.06	....	3.47	...	....	....	8532	15,358	Mahler
Unknown (anthracite)	....	....	93.44	1.48	4.61	0.47	...	1.9	2.0	7145	12,861	Alexejew
NEW CALEDONIA												
Noumea	82.75	6.25	....	...	....	....	...	....	11.00	7199	12,958	L. Peletan
Noumea	62.20	32.00	....	...	....	....	...	....	5.30	6159	11,086	"
Monedon	74.23	26.00	....	...	....	....	...	....	1.77	6842	12,326	"
	86.50	6.50	....	...	....	....	...	....	7.00	7037	12,667	"
Vok	78.25	9.00	....	...	....	....	...	....	12.75	6885	12,393	"
NOVA SCOTIA												
Cooperstown	65.16	30.75	....	...	....	....	...	....	4.09	8944	16,100	Carpenter
Cape Breton	....	....	....	...	....	....	...	....	7.8	6947	12,505	Barrus
Nova Scotia	63.61	32.38	....	...	....	....	...	....	4.11	8889	16,000	Carpenter
ONTARIO												
Sudbury (Anthraxolite)	....	0.52	94.92	...	1.69	1.04	0.31	4.00	1.52	8141	14,654	W. H. Ellis and W. Lawson

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
RUSSIA												
Gagul	....	....	78.27	4.46	16.31	0.96	...	....	....	7302	13,144	Alexejew
Tkwebuli, Caucasus	....	....	78.42	5.13	15.41	1.04	...	....	....	7525	13,245	"
Sosna, Altai	....	....	78.90	5.61	13.05	2.44	...	....	....	7600	13,680	"
Werckne Gubach, Ural	....	....	82.56	5.44	11.04	0.96	...	....	....	8116	14,609	"
Rutschenkowo, Donetz	....	....	83.23	5.01	10.06	1.70	...	....	....	8230	14,814	"
Kamensk Wks	....	....	90.28	4.90	3.82	1.00	...	....	....	8200	14,760	"
Kirghis Steppes	....	....	60.42	4.00	35.15	0.43	...	....	....	4860	8,748	"
Rutschenkvo	....	....	83.43	4.98	10.82	0.77	...	....	....	8190	14,742	Alexejew
Magatoch, Saghalien	....	47.13	71.51	5.51	15.25		0.78	4.74	2.05	7888	14,198	Miklaschewski
" "	....	41.55	65.78	5.43	14.20		0.97	5.85	7.77	7615	13,707	"
Nagassi, Saghalien	....	29.27	69.22	5.06	8.45		0.68	1.17	15.42	8609	15.296	"
Sutschan, Saghalien	....	7.85	86.75	4.44	1.59		0.93	0.73	5.56	8703	15,665	"
Menselinsk, on the Kama	31.5	....	61.51	5.81	32.70	0.98	...	20.3	9.2	5830	10,494	Alexejew
Petchora	44.9	....	65.71	4.11	28.85	1.33	...	8.1	3.6	5792	10,426	"
Malewka, Tula	42.9	....	68.66	4.89	25.43	1.02	...	6.4	22.6	6565	12,117	"
" Boghead," Tula	19.9	....	77.38	10.14	18.82	0.66	...	0.3	23.6	9104	16,387	"
Tshulkowo, Riasan	50.5	....	72.65	5.14	21.30	0.91	...	5.8	12.2	6918	12,452	"
" Boghead;" Riasan	13.6	....	70.00	8.56	20.59	0.85	...	1.9	9.1	8595	15,471	"
Zerghana	64.3	....	73.75	4.33	21.26	0.68	...	8.5	2.0	6821	12,278	"
Jegorshino, Ural	....	....	92.34	3.45	3.05	1.16	...	1.3	3.1	8267	14,381	"
Orsk	....	....	93.56	1.52	4.18	0.74	...	4.1	20.6	7840	14,112	"
Gruschewka, Don	....	....	94.56	1.20	1.05	0.81	...	3.5	1.9	7502	13,504	"
Shunga, Onega Lake	....	....	93.45	0.99	4.86	0.70	...	4.1	8.3	7415	13,147	"
Bajewka, Ural	....	....	97.46	0.61	1.58	0.35	...	0.0	1.4	7440	13,192	"
Bajewka, Ural (graphitic)	....	....	95.60	0.49	3.40	0.55	...	6.8	19.6	7502	13,504	"
Albeeldt (asphaltic)	42.9	....	84.91	8.67	3.87	2.55	...	....	....	9433	16,979	"
Helat, Caucasus	60.4	....	75.50	4.77	17.92	1.80	...	....	....	7120	12,816	"
" "	44.7	....	74.74	5.79	18.67	0.80	...	....	....	7554	13,597	"

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
SCOTLAND												
Bannockburn Main	68.10	27.40	82.80	5.14	5.67		1.89	1.75	2.75	8624	—5,523	Anderson & Roberts
Hamilton (Ell)	55.70	33.33	71.88	4.52	11.10		1.53	9.99	0.98	8402	15,124	"
" (Gas)	52.49	38.25	76.16	5.54	7.52		1.52	5.56	3.70	8122	14,620	"
" (Main)	53.79	33.84	73.62	4.98	9.50		1.54	9.08	1.28	8467	15,241	"
" (Splint)	54.31	36.22	75.50	4.82	8.71		1.50	7.27	2.20	8202	14,764	"
" (Virgin)	56.40	33.53	74.67	5.10	8.62		1.54	7.77	2.30	8328	14,990	"
Kilsyth (coking)	67.82	28.45	81.50	5.20	7.53		2.04	1.72	2.01	8113	14,603	"
Haughrigg	62.52	32.55	80.67	5.06	7.50		1.84	1.98	2.95	7927	14,269	"
Kiltongue, Airdrie	52.91	35.25	73.30	5.37	7.83		1.65	10.45	1.40	7773	13,991	"
Lower Drumgray, Airdrie, I	54.51	36.78	75.17	5.02	9.92		1.45	7.14	1.30	7839	14,110	"
" " " II	60.16	33.81	77.33	5.00	9.78		1.90	4.02	1.97	7887	14,097	"
" " " III	73.56	20.61	83.87	4.37	3.81		2.12	1.83	4.00	8294	14,929	"
Upper Drumgray, Airdrie, I	51.91	40.27	77.14	5.68	7.71		1.65	4.70	3.12	8144	14,659	"
" " " II	57.54	35.83	77.17	4.66	9.57		1.88	3.82	2.90	7901	14,222	"
Virtuewell, Airdrie	49.58	37.73	71.83	4.97	8.80		1.68	6.90	5.82	7971	14,348	"
SPAIN												
Aller Coal												
Prevenida	82.8	17.2	....	....	....	....	...	....	4.28	7350	13,230	R. Oriol
Vicentera	82.7	17.3	....	...	....	....	...	....	5.10	7200	12,960	"
Legalidad	81.4	18.6	....	...	....	....	...	....	4.15	7400	13,320	"
Juanon	79.1	20.9	....	...	....	....	...	....	4.90	7190	12,942	"
Gabriela	77.7	22.3	....	...	....	....	...	....	4.80	7120	12,816	"
Conveniencia	83.7	16.3	....	...	....	....	...	....	3.95	7250	13,050	"
Ignacia	82.2	17.8	....	...	....	....	...	....	4.15	7180	12,924	"
Dos Demigos	83.1	16.9	....	...	....	....	...	....	4.30	7230	13,014	"
Esperanza	77.2	22.7	....	...	....	....	...	....	4.89	7035	12,663	"
Petrita	77.2	22.8	....	...	....	....	...	....	5.10	7010	12,618	"
Mariano	81.9	18.1	....	...	....	....	...	....	4.50	7330	13,194	"
Molino	81.7	18.3	....	...	....	....	...	....	3.80	7180	10,924	"
Catalanas	78.8	21.2	....	...	....	....	...	....	4.15	7110	12,798	"

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
SPAIN—*Continued*												
Castile												
Joven Ilvefonso, San Obrian	73.91	26.09	....	...	....	....	...	....	8.00	6954	12,517	R. Oriol.
Catalina, San Obrian	73.19	26.81	....	...	....	....	...	...	8.60	6930	12,474	"
San Cabrian, San Obrian	78.42	21.58	....	...	....	....	...	....	10.80	7162	12,892	"
Verdeña, La Permia	58.16	41.84	....	...	....	....	...	....	4.40	5309	9,556	"
San Felice	74.36	25.64	....	...	....	....	...	....	7.00	7075	12,735	"
Villanueva, La Peña	88.36	11.64	....	...	....	....	...	....	2.08	7615	13,707	"
Villaverde (average of 6)	90.35	9.65	....	...	....	....	...	....	12.32	7281	13,105	"
Transpeña	91.90	8.10	....	...	....	....	...	....	3.64	7452	13,413	"
Valdelora, Carrion	89.43	10.57	....	...	....	....	...	....	5.40	7529	13,552	"
Valdecastro	92.95	7.05	....	...	....	....	...	....	3.60	7705	13,969	"
Metalacasillo	84.88	15.72	....	...	....	....	...	....	8.90	7476	13,457	"
Valdecorcas	87.00	12.99	....	...	....	....	...	....	2.06	6780	12,604	"
Censol Menor	80.00	20.00	....	...	....	....	...	....	6.00	7395	13,211	"
Valdespiña, Cea River	92.10	7.90	....	...	....	....	...	....	3.80	7796	14,033	"
Tarancilla	90.72	9.28	....	...	....	....	...	....	0.84	7049	12,692	"
Mosquitera, Asturia	60.05	39.95	....	...	....	....	...	....	3.60	6176	11,117	"
Sama	62.40	37.60	....	...	....	....	...	....	2.50	6345	11,421	"
Maria Louisa	64.40	35.60	....	...	....	....	...	....	2.55	6738	12,128	"
La Jurter	68.00	32.00	....	...	....	....	...	....	2.40	7214	12,985	"
Santa Barbara	76.11	23.89	....	...	....	....	...	....	3.12	7320	13,176	"
Coto de Aller	83.20	10.80	....	...	....	....	...	....	5.14	7841	14,113	"

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
NEW ZEALAND												
Brown coal, Malvern, Canterbury	53.29	32.04	....	...	....	....	...	12.65	2.02	7650	13,870	Journal Iron and Steel Institute.
" " "	49.99	35.42	....	...	....	....	...	11.79	2.80	7338	13,208	"
" " "	47.70	30.92	....	...	....	....	...	19.20	2.20	7444	13,379	"
" Rokaia Gorge "	50.12	21.61	....	...	....	....	...	24.09	4.18	8751	15,752	"
" Westport.....	56.01	37.17	....	...	....	....	...	2.60	4.22	7545	13,481	"
" "	57.92	34.94	....	...	....	....	...	3.96	3.18	7953	14,315	"
" Waikato, Auckland .	50.01	29.97	....	...	....	....	...	19.82	2.20	7948	14,306	"
" Shag Point, Otago..	45.30	30.10	....	...	....	....	...	19.20	5.40	7250	13,050	"
" Kaitangata, " ..	44.11	38.32	....	...	....	....	...	15.44	2.13	6725	12,105	"
" " " ..	39.41	27.25	....	...	....	....	...	19.61	3.73	6451	11,612	"
" Okoko, Auckland...	39.83	33.74	....	...	....	....	...	22.21	4.22	6772	12,190	"
" Springfield, Colliery.	38.00	31.50	....	...	....	....	...	18.60	11.90	6809	12,256	"
Bituminous, Gray River, Westl'nd	62.37	29.44	....	...	....	....	...	1.99	6.20	8425	15,165	"
" Preservation Inlet..	60.88	20.69	....	...	....	....	...	4.33	6.19	8536	15,364	"
" Westport.....	59.75	32.14	....	...	....	....	...	3.97	4.14	8155	14,679	"
" Mokihinui.....	55.59	38.86	....	...	....	....	...	3.16	2.39	7362	13,252	"
" Brunner Mine.....	56.62	35.68	....	...	....	....	...	1.59	6.11	7701	13,862	"
" Otamatawea Creek.	52.89	36.63	....	...	....	....	...	2.19	8.29	8328	14,990	"
" Cape Farewell.....	48.59	43.17	....	...	....	....	...	2.18	6.06	6970	12,546	"
" Ross, Southland....	42.53	31.43	....	....	....	....	...	6.58	19.26	5470	9,846	"
Glance coal, Whangaree, Auckland.....	50.11	38.68	....	...	....	....	...	8.01	3.20	7070	12,726	"
Black coal, Kawa River.....	50.15	42.63	....	...	....	....	...	4.18	3.04	6786	12,215	"
Pitch coal, Grey River, Westland	60.20	29.97	....	...	....	....	...	8.01	1.81	8375	15,075	"
" " Whangaree.....	50.01	37.69	....	...	....	....	...	9.61	2.69	7157	12,882	"

COLLIERY REFUSE

R. S. Fernald, discussing the use of low-grade fuels in Europe, gives in Technical Paper 123 of the U. S. Bureau of Mines analyses and calorific values of colliery refuse. The refuse containing shale and coal is crushed, mixed and washed and then used in gas producers. Samples of the fuel were analyzed at the Bureau of Mines with the results given in the accompanying table:

ANALYSIS AND CALORIFIC VALUE OF REFUSE FUEL

As Taken from Dump

Condition of Samples.	Proximate Analysis.				Ultimate Analysis.					Air-drying Loss.	Calorific Value.	
	Moisture.	Volatile.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.		Calories.	B.T.U.
As received	6.99	18.37	22.52	52.12	0.56	3.17	29.73	0.71	10.13	3.6	2814	5,065
Air-dry	3.55	19.05	23.35	54.05	0.58	2.87	30.83	0.74	13.71	...	2918	5,252
Moisture-free	....	19.75	24.21	56.04	0.60	2.57	31.97	0.76	8.06	...	3026	5,447
Moisture- and ash-free	....	44.93	55.07	.....	1.36	5.85	72.73	1.73	18.33	...	6884	12,391

After Washing

As received	5.86	28.75	40.79	24.60	1.13	4.41	56.17	1.30	13.29	2.7	5483	9,869
Air-dry	3.25	29.55	41.92	25.28	1.16	4.22	57.73	1.34	10.27	...	5635	10,143
Moisture-free	....	30.54	43.33	26.13	1.20	3.99	59.66	1.38	7.64	...	5824	10,483
Moisture- and ash-free	....	41.34	58.66	.....	1.62	5.40	80.76	1.87	10.35	...	7884	14,191

LIGNITE

From an industrial standpoint lignite is of considerable importance. It occurs in most countries, and is used in a great many for domestic and manufacturing purposes.

As a fuel it is inferior to coal, being less distantly removed from woody fiber, and hence contains more hydrogen and, usually, considerable water. Most of the latter, however, dries out on

exposure to the air. In some cases as much as 40 or 50 per cent of water is found in the freshly mined lignite, of which at times 20 per cent remains when air-dried. This greatly affects its value as fuel; still it is used in many of the Western States, and also in Europe. In some European localities, when thoroughly dried and compressed into blocks, especially in Italy and Austria, it is used as fuel for producing gas and for evaporating, with good results. In Austria it is burned without any preparation, except drying in the air, for heating salt-pans.

The amount of ash varies exceedingly, being in some cases as low as 0.9 per cent, and in others as high as 58 per cent. It even varies in the same locality and in the same bed. In burning lignite there is considerable loss in the waste gases on account of the large quantity of air introduced, and also from the moisture carried off from the fuel.

The lignites of Western America resemble the "brown coals" of Europe in holding a large amount of water. The percentage ranges from 4 to 20 per cent, being from 12 to 15 per cent in most cases. The percentage of ash is from 2 to 9 per cent, while sulphur is generally below 1 per cent. Texas lignites, according to Bulletin 189 of the University of Texas, range from a few per cent of fixed carbon to nearly 45 per cent, and with from 30 per cent volatile matter to more than 76 per cent. The following analyses show the extreme range of composition and the average of fifteen mine samples:

COMPOSITION AND CALORIFIC VALUE OF TEXAS LIGNITES

	Moisture.	Vol.	F.C.	Ash.	S.	C.	H.	O.	N.	B.T.U. per Lb. as mined.	B.T.U. per Lb. Combustible.
Milam Co....	29.1	29.0	24.5	17.6	3.3	38.7	2.7	7.3	1.4	7439	13,900
Hopkins Co...	33.9	45.9	3.4	16.8	0.7	34.1	2.3	11.1	1.1	6474	13,130
Av. of 15....	33.0	40.4	17.2	9.0	1.1	40.1	3.0	12.3	1.2	7614	13,310

Another series of 23 samples received from mining companies gave moisture 7.3 to 37.3, av. 25.2; volatile matter 20.3 to 45.6, av. 37.6; fixed carbon 21.1 to 38.9, av. 28.5; ash 4.8 to 6.1, av. 8.8. B.T.U. per lb. as received 6291 to 10,411, av. 7661 B.T.U. per lb.

Brix published the following results with dried lignite:

	Water Evaporated.	Per Cent Ash.
Lignite of Aussig, Bohemia	5.8 lb.	15.0
" " Perleberg, Bohemia	5.6	6.0
" " Goldfuchs n. Frankfort	5.5	9.1
" " Rauen	5.4	6.3

Bunte used two kinds of lignite in boiler-tests, and gives the following results:

	Neusattel.	Chodan.
Calories in steam	42.8	49.2
" " gases	19.6	21.0
" " aqueous vapor	9.2	8.7
" " ash	9.0	6.1
" unaccounted for	19.4	15.0

The grate used was a step grate (Treppen-Rost).

The lignite used on the railways in Italy contained 15 per cent of water, and gave a yield of heat equal to one-half its weight of coal.

Analogous to the lignites are certain shales or fossils carrying bitumen. They are sometimes termed *boghead cannel, bituminous schist,* etc. They are distilled in some localities for oil, but are not much used as fuel.

Bunte determined the heat of combustion of a sample from Australia, and analyzed one from Scotland.

	Carbon.	Hydrogen.	O + N.	Calories.
Boghead shale, Australia	83.17	10.04	6.79	9134
Scotch Boghead	81.54	11.62	6.84	

Scotch Boghead usually contains 18 to 24 per cent of ash. From its analysis as above, its heat of combustion should be near that of the other one given.

Burning Lignites. (E. J. Babcock, *Bulletin* 89, *U. S. Bureau of Mines.*) Lignite is commonly burned with too high a percentage of moisture. As taken from the mine it usually contains more than 25 per cent moisture and should be seasoned and broken

into lumps of uniform small size before being put on the market. If this is done before the lignite is allowed to dry the loss in slack is much reduced. A series of analyses to determine the effect of weathering showed that at the end of a 14-day period the moisture had been reduced from 33.5 to 12.52 per cent; volatile matter had increased to 34.83 from 25.5 and fixed carbon had increased to 46.05 from 35 per cent.

The proper combustion of lignite depends on the size of the lumps, its structure being such as to give abundant air surface. In addition the draft should be easily controlled and capable of being closely shut down when it is desired to hold the fire at a relatively low heat. The fire box should be reasonably well filled, but firing should be done frequently by the application of thin layers of fuel. Clinker and ash should not be allowed to accumulate.

Producer Gas from Lignite. Producer gas made from North Dakota lignite during the World's Fair at St. Louis in a model producer gas plant operated by the Government showed most satisfactory results.

The table herewith shows the composition and calorific value of producer gas made from several different grades of lignites:

COMPOSITION AND CALORIFIC VALUE OF LIGNITE PRODUCER GAS

	North Dakota Lignite.	Texas Lignite.	Colorado Lignite.
CO_2	8.69	11.10	10.11
CO	20.90	14.43	17.38
H	14.33	10.54	11.05
CH_4	4.85	7.48	5.0
N	51.02	56.23	55.91
B.T.U. per cubic foot	164.1	169.7	149.0

Tests of twenty-five representative lignites including those from North Dakota, Montana, Colorado and Texas were made by the United States Bureau of Mines and showed a yield of unpurified gas ranging from 13,297 cu.ft. to 7825 cu.ft. per ton of air-dried lignite. The calorific value of the gas ranged from 487 to 285 B.T.U. per cubic foot. The average of the twenty-five tests was a yield of 11,038 cu.ft. of gas per ton of air-dried lignite and a calorific value of 396 B.T.U. per cubic foot.

ANALYSES AND HEATING VALUE OF EUROPEAN LIGNITES

Name or Location.	Carbon.			Hydrogen.	Oxygen, Nitrogen and Sulphur.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.								Calories.	B.T.U.	
Freienstein, Austria	....	....	72.12	4.83	23.05	....	....	...	....	....	6472	11,650	Schwackhöfer
Briex, Austria	....	....	71.78	4.93	23.29	....	....	...	....	....	6638	11,950	"
Koeflach, Austria	....	....	67.93	5.45	26.62	....	....	...	....	....	6096	10,973	"
Pankraz, Bohemia	....	....	82.23	4.61	13.16	....	....	...	....	....	7604	13,687	"
Bilin, Bohemia	....	....	72.17	5.49	22.34	....	....	...	....	....	6364	11,731	Bunte
Bustehrad-Kladno, Bohemia	....	....	79.94	4.41	15.65	....	....	...	....	....	7448	13,407	Schwackhöfer
Fat lignite, Bohemia	....	....	76.58	8.27	15.15	....	....	...	....	....	7924	14,263	Scheurer-Kestner
Rocher-Bleu, France	....	....	72.98	4.04	22.98	....	....	...	....	....	6480	11,664	"
Manosque, France	....	....	70.57	5.44	23.99	....	....	...	....	....	7363	13,253	"
Manosque, France	....	....	66.31	4.85	28.84	....	....	...	....	....	6991	12,584	"
Toula, Russia	....	....	73.72	6.09	20.19	....	....	...	....	....	7687	13,837	"
Salgo-Tarjan, Hungary	....	....	72.78	5.33	21.89	....	....	...	....	....	6951	12,511	Schwackhöfer
Dodosè, Kralyrani, Hungary	....	....	47.2	4.25	....	18.15		...	19.20	11.20	6244	11,239	Prziwoznik
Ilz, Hungary	....	....	49.1	4.23	....	24.07		...	9.15	13.45	5372	9,670	"
Nagy Kavocsi, Hungary	....	....	51.6	4.10	....	19.80		...	15.60	8.90	6074	10,933	"
Pernik, Bulgaria	41.91	35.07	....	....	....	....	....	1.86	12.47	8.74	5818	10,472	Anonymous
Kirghis Steppes, Russia	....	....	60.42	4.00	....	35.15	0.43	...	....	....	4860	8,748	Alexejew
Kirghis Steppes, "	....	....	62.79	5.56	....	31.39	0.20	...	....	....	5875	10,475	"
Brown, coal, Bilin, Germany	23.33	47.83	....	3.75	....	15.23	....	...	25.92	2.92	6090	10,962	Bunte

PEAT

Peat is partly decomposed, and disintegrated vegetable matter that has accumulated in any place where the ordinary decay or decomposition of any material has been more or less suspended, although the form and a considerable part of the plant structure are more or less destroyed. It is formed by the agglomeration of vegetable *débris*, and retains a large amount of water, which will not separate without heat. Its composition varies but little from that of wood, the principal difference being less oxygen and more carbon.

The composition may be represented by—

Carbon	60
Hydrogen	6
Oxygen and nitrogen	34
	100

The heat of combustion is lower than that of coal or lignite, as might be expected. The quantity of hydrogen exceeds that necessary to form water with the oxygen.

It is usually dried before using, and when dry becomes quite porous. It carries, however, in this state some 10 to 15 per cent of water, which can be expelled only by artificial means. Large quantities of it are converted into charcoal in special kilns, and, where the large amount of ash is no objection, it makes a good fuel. It cannot be used for metallurgical purposes on account of its friability. From 30 to 40 per cent of its weight is left in the charcoal as carbon, but at the same time the ash increases to 15 to 25 per cent, and even more. This consists principally of phosphates and sulphates, with very little carbonates; hence it is not as apt to clinker as other fuel ashes.

The calorific value of a given peat sample in terms of theoretically dry peat may be approximately reduced to that of any desired water content between 0 and 30 per cent by deducting 1 per cent from the theoretical value for each 7 per cent of moisture present. Thermal value of dried peat can be determined from the thermal value of peat with a given percentage of moisture by the formula:

$$\frac{\text{Calorific Value as analyzed}}{100-\%\text{ of } H_2O \text{ found by analysis}} \times 100 = \text{Calorific value of moisture-free peat.}$$

Bulletin 16, U. S. Bureau of Mines, presents a table giving the calorific value of the common types of fuel as compared with several varieties of air-dried peat. This table is condensed below:

RELATIVE VALUE OF PEAT AND OTHER FUELS

Type of Fuel.	Calories.	B.T.U.
Graphitic anthracite from Cranston, R. I.	6109	10,996
St. Nicholas, Pa.	6870	12,366
Semi-anthracite, Spadra, Ark.	6922	12,460
Semi-bituminous, Ennis, W. Va.	7939	14,290
Pittsburgh bituminous, Connellsville, Pa.	7525	13,365
Lignite, Olsen, Texas	4372	7870
Brown peat, Fremont, N. H.	5161	9290
Light brown fibrous peat, Rochester, N. H.	5042	9083
Dark brown fibrous peat, Westport, Conn.	4772	8590
Brown fibrous peat, Cicero, N. Y.	4209	7576
Brown fibrous peat, LaMartine, Wis.	4149	7468
Salt marsh peat, Kittery, Me.	4066	7319
Brown sandy peat, Kent, Conn.	3291	5924
Black peat, New York State	2867	5161

The characteristics determining the fuel value of peat are the ash and water content, degree of decomposition, density and color. The heating value diminishes nearly in proportion to the quantity of ash and moisture present. In general, finer-grained compact, dark-colored peats are better than those of coarse, fibrous or woody texture.

Freshly dug peat from undrained deposits may contain as high as 90 per cent water and as low as 3 per cent carbonaceous materials, together with a highly variable percentage of ash. Freshly dug wet peat has such low heating value that it must be partially dried before it can be burned. Perfectly dried peat of good quality can be burned in a large combustion chamber with ample draft to develop a temperature of about 4000 deg. Fahr.

The water content of air-dried peat will vary considerably according to the season. The lowest limit of moisture in the central part of the United States will probably be at least 8 per cent; while on the New England coast it will range in the neighborhood of 25 per cent.

Peat of the heavier and denser qualities freshly cut from undrained beds weighs from 70 to 75 lb. per cubic foot, while continued drying in sun and wind will decrease its weight to from 8 to 25 per cent of the original quantity. During the drying, the peat may shrink to $1/4$ of it original bulk.

The following table shows the effect of the moisture and ash on good and poor peats:

Ash, Per Cent.	Water, Per Cent.	Calorific Value, per Lb., B.T.U.
Free	Free	10,726
4	Free	10,297
4	11	9,117
4	15	8,688
4	25	7,615
4	30	7,079
4	50	4,934
10	Free	9,653
20	Free	8,581
10	15	8,045
10	20	7,508
20	15	6,973
20	20	6,436

The table on page 113 gives the analysis and calorific values of various foreign peats.

Brix obtained with peat an evaporative power of 5.11 lb. of water. The peat used was from Flatow, and contained 10.7 per cent of ash. Another, from Buchfeld-Neulangen, contained 1.2 per cent of ash, and gave 5.12 lb. evaporation. Noury, using a special grate, obtained from the Alsace peats 4 to 5 lb. evaporation (ashes deducted).

Bunte analyzed the gases produced by the combustion of peat on the hearth of a salt-pan, and found: carbonic acid 13, oxygen 6.4, nitrogen 80.6.

Crookes and Rohrig, in their " Metallurgy," say " One pound of dry turf will evaporate 6 lb. of water. Now in 1 lb. of turf, as usually found, there are $^3/_4$ lb. of dry turf and $^1/_4$ lb. of water. The $^3/_4$ lb. can evaporate $4\frac{1}{2}$ lb. of water; but out of this it must first evaporate the $^1/_4$ lb. of water contained in its mass, and hence the water boiled away by such turf reduces to $4\frac{1}{4}$ lb. The yield is here reduced 30 per cent, a proportion which makes all the difference between a good fuel and one almost unfit for use. When turf is dried in the air under cover it still retains $^1/_{10}$ of its weight of water, which reduces its calorific power 12 per cent; 1 lb. of such turf evaporates $5\frac{1}{3}$ lb. of water.

It is evident from the above table that but little appreciable change has been made in the heat value by the different kinds

of treatment and therefore, except for the greater compactness and hardness obtained the cost of briqueting is not justified.

Peat Coke. Coke has been made from peat. The best peat coke is black and has a luster of jet. It is hard and compact but retains the original structure of macerated peat. The percentages of sulphur and phosphorus are usually low and with good peat the ash content is also low. Peat coke will give a temperature of about 4300 deg. Fahr. when burned under proper conditions. This is about the same temperature that can be obtained with good dry coal. The calorific value of peat coke ranges from 12,000 to 14,000 B.T.U. per pound.

Preparation of Peat. Peat is used in both dust and briqueted form. Peat that is reduced to a powdered form has a larger percentage of volatile matter than coal, burns with a hot flame and is well adapted for use in powder burners. It also ignites at a lower temperature than coal.

Briqueted peat is clean, compact and dense. The briquets occupy less space and are more easily stored than the same weight of peat in any other form. They burn less rapidly than cut or machine peat and hence give less trouble in firing than do other kinds of peat fuel.

They, however, will crumble whenever handled and are disintegrated by exposure to moisture. Experiments made on peat from the deposit at Black Lake, N. Y., to show the effect on the heating value of the method of preparation gave the results indicated in the following table:

EFFECT OF METHOD OF PREPARATION OF PEAT

Character of Fuel.	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Heating Value.	
						Calories.	B.T.U.
Raw peat:							
Air-dried	.....	50.92	23.79	16.61	0.99	4179	7522
Moisture-free	8.68	55.77	26.04	18.19	1.08	4576	8237
Machine peat:							
Air-dried	.....	49.85	23.35	17.47	0.89	4055	7299
Moisture-free	9.33	54.97	25.77	19.26	0.98	4472	8050
Dry powder for briqueting:							
Air-dried	.....	52.03	22.74	17.86	0.96	4102	7384
Moisture-free	7.37	56.17	24.53	19.30	1.03	4428	7971
Briqueted steam dried peat							
Air-dried	.....	52.19	32.44	17.37	1.16	4193	7547
Moisture-free	8.0	56.73	24.39	18.88	1.27	4557	8203

CALORIFIC VALUE AND ANALYSES OF PEAT *

(Bulletin No. 16, U. S. Bureau of Mines, 1911)

Location.	Proximate Analysis.			Calorific Value.	
	Volatile.	Fixed Carbon.	Ash.	Calories.	B.T.U.
CONNECTICUT:					
Fairfield County	63.70	31.58	4.72	5466	9,839
Fairfield County	24.78	9.95	65.27	1902	3,424
Litchfield County	56.38	36.31	7.31	5252	9,454
Litchfield County	16.80	5.71	77.49	997	1,795
Middlesex County	61.00	32.46	6.54	5414	9,745
Middlesex County	16.37	6.08	77.55	949	1,708
New Haven County	75.11	20.91	3.98	5634	9,655
New Haven County	30.44	10.64	58.92	2293	4,127
New London County	61.17	31.58	7.25	5556	10,001
New London County	32.34	16.60	51.06	2647	4,765
Windham County	58.93	33.09	7.98	5095	9,171
Windham County	58.31	33.60	8.09	5011	9,020
FLORIDA:					
Citrus County	60.17	27.46	12.37	5184	9,331
Dade County	11.42	38.53	50.05	668	1,202
Dade County	56.31	34.46	9.23	5384	9,691
De Soto County	59.79	30.50	9.71	5230	9,414
Duval County	27.10	15.86	6.85	2517	4,531
Duval County	48.44	25.88	25.68	4324	7,783
Hernando County	56.41	28.07	15.52	5867	10,561
Hernando County	23.55	12.99	63.46	1870	3,366
Lake County	67.80	30.67	1.53	6036	10,865
Lake County	53.61	24.45	21.94	2716	4,889
Leon County	63.07	29.38	7.55	5244	9,439
Leon County	65.29	30.43	4.28	5413	9,743
Polk County	63.57	33.38	3.05	5855	10,539
Polk County	38.26	24.85	36.89	3534	6,361
Putnam County	52.80	38.29	8.91	5235	9,423
Putnam County	50.57	32.88	16.55	4802	8,644
Santa Rosa County	20.44	11.90	67.66	1610	2,898
Santa Rosa County	13.45	6.81	79.74	1443	2,597
MAINE:					
Androscoggin County	60.22	33.79	5.99	5238	9,428
Androscoggin County	.....	.....	4.48	3256	5,861
Aroostook County	.....	.....	5.99	5411	9,740
Aroostook County	.....	.....	9.41	5093	9,167
Cumberland County	61.67	31.41	6.92	5005	9,009
Cumberland County	60.11	28.89	11.00	4656	8,381
Hancock County	58.63	34.88	6.49	5126	9,227
Hancock County	.....	.....	5.21	4800	8,640
Kennebeck County	63.11	31.99	4.90	5402	9,724
Kennebeck County	.....	.....	32.95	3905	7,029
Knox County	66.12	29.74	4.14	4956	8,921
Knox County	.....	.....	19.70	4374	7,873
Oxford County	57.66	33.91	8.43	4938	8,888
Oxford County	56.84	19.13	24.03	4336	7,805
Penobscot County	63.06	31.21	5.73	5350	9,630
Penobscot County	.....	.....	18.46	4517	8,131
Somerset County	.....	.....	4.45	5832	10,498
Somerset County	.....	.....	25.03	4082	7,348
MAINE:					
Washington County	59.95	31.93	8.12	5433	9,779
Washington County	.....	.....	9.62	4559	8,206
York County	56.72	29.36	13.92	4701	8,462
York County	29.88	12.31	57.81	2019	3,634

* Where more than one analysis from a county is given, in the original table, the peats showing the maximum and minimum heating value have been selected for this table. The original table gives values also of the raw peat containing moisture. The values above are for moisture-free peat.

CALORIFIC VALUE AND ANALYSES OF PEAT—*Continued*

Location.	Proximate Analysis.			Calorific Value.	
	Volatile.	Fixed Carbon.	Ash.	Calories.	B.T.U.
MASSACHUSETTS:					
Essex County	58.79	29.65	11.56	5079	9,142
Hampshire County	57.04	34.61	8.35	5171	9,308
Hampshire County	57.51	33.72	8.77	5126	9,227
Middlesex County	54.13	30.69	15.18	4813	8,663
MICHIGAN:					
Allegan County	42.54	18.03	39.43	3247	5,845
Kalamazoo County	60.77	32.22	7.01	5570	10,026
Kalamazoo County	57.54	28.07	14.39	5077	9,139
Livingston County	65.00	28.74	6.26	5306	9,551
Monroe County	60.40	29.75	9.85	5086	9,155
NEW HAMPSHIRE:					
Rockingham County	62.02	29.51	8.47	5511	9,920
Rockingham County	31.00	14.24	54.76	2248	4,046
Strafford County	66.74	28.67	4.59	5711	10,280
Strafford County	49.70	23.49	26.81	4225	7,605
NEW YORK:					
Essex County	64.94	31.90	3.16	5604	10,087
Franklin County	67.10	28.99	3.91	5726	10,307
Franklin County	49.67	14.99	35.34	3675	6,615
Livingston County	60.37	25.80	13.83	4600	8,280
Madison County	60.44	27.40	12.16	4348	7,826
Onondaga County	64.14	27.17	8.69	4927	8,869
Onondaga County	26.25	10.46	63.29	1953	3,515
Orleans County	58.49	24.21	17.30	4542	8,176
Orleans County	56.94	12.58	30.48	3067	5,521
Oswego County	64.29	27.44	8.27	5029	9,052
Oswego County	33.99	18.78	47.23	2750	4,950
St. Lawrence County	55.77	26.04	18.19	4576	8,237
St. Lawrence County	56.17	24.53	19.30	4428	7,971
Steuben County	49.91	23.61	26.48	4023	7,241
NORTH CAROLINA:					
Pasquotank County	51.88	28.83	19.29	4583	8,249
WISCONSIN:					
Ashland County	61.15	27.02	11.83	5081	9,146
Chippewa County	57.99	27.59	14.42	4947	8,905
Dane County	54.93	27.60	17.47	4912	8,842
Dane County	23.69	5.91	70.40	1449	2,608
Door County	60.15	17.80	22.05	4388	7,898
Fond du Lac County	53.45	27.93	18.62	4607	8,293
Fond du Lac County	57.98	24.72	17.30	4527	8,149
Iron County	56.76	27.10	16.14	4534	8,161
Kewaunee County	59.25	25.92	14.83	4448	8,006
Kewaunee County	41.65	16.42	41.93	3270	5,886
Longlade County	46.61	21.10	32.29	3532	6,358
Lincoln County	55.90	21.31	22.79	4473	8,051
Manitowoc County	56.13	22.99	20.88	4326	7,787
Manitowoc County	52.42	17.33	30.25	3677	6,619
Marinette County	55.75	25.52	18.73	4353	7,835
Marinette County	45.60	19.71	34.69	3519	6,334
Oconto County	63.38	28.26	8.36	5109	9,196
Oconto County	59.15	27.68	13.17	4340	7,812
Oneida County	62.77	27.71	9.52	5217	9,391
Price County	44.59	19.74	35.67	3640	6,552
Rusk County	56.16	21.82	22.02	4418	7,952
Sawyer County	56.54	27.92	15.54	4867	8,761
Sawyer County	55.40	21.74	22.86	4460	8,028
Sheboygan County	63.28	25.28	11.44	4863	8,753
Vilas County	63.44	25.39	11.17	5198	9,356
Vilas County	54.41	19.72	25.87	4213	7,583
Waupaca County	58.29	25.18	16.53	4545	8,181
Waupaca County	59.23	14.60	26.17	4147	7,465

CALORIFIC VALUES OF FOREIGN PEATS

Location.	Carbon.	Hydrogen.	Oxygen and Sulphur.	Ash.	Water.	Coke.	Calories.	B.T.U.	Authority.
Ismaning, Bohemia	39.26	3.88	22.93	7.27	26.26	28.00	3246	5,843	Bunte
" " (pure)	63.13	5.88	30.99	....	.....	31.42	4978	8,960	
Rosenheim, Bohemia	44.08	4.54	28.34	2.00	21.04	27.4	4115	7,407	
" " (pure)	57.27	5.89	36.84	....	.....	33.02	5347	9,625	
Zengermoos, Bohemia	40.82	4.43	26.58	7.72	20.84	?	3774	6,793	
" " (pure)	59.14	6.24	36.62	....	.....	?	5283	9,509	
Bohemia (locality not given)	53.18	5.54	34.23	0.93	6.12	31.7	5489	9,880	
" (pure)	57.21	5.96	36.83	....	.....	.....	5903	10,625	
Dried peat	.....	....	.....	....	.....	.....	5940	10,692	Bainbridge
Moist peat	.....	....	.....	....	.....	.....	4675	8,415	
Bohemia	53.19	5.54	34.23	0.92	6.12	.....	5903	10,625	Mahler
Ireland (dry)	59.00	6.00	30.00	4.00	.....	.....	5700	10,260	Berthelot and Petit
" (moist)	.....	....	.....	....	.....	.....	4106	7,391	

COKE

Coke is generally obtained from three sources: by the destructive distillation of gas-coal, in gas-retorts; by the destructive distillation of gas or ordinary bituminous coal, in special ovens of the beehive or by-product type; from petroleum, being made by carrying the distillation of the residuum to a red heat.

Coke from gas-works is usually softer and more porous than the other kinds, burns more readily, but does not give as intense a heat. It has had considerable use for domestic heating, and in factories where a high heat is not needed but where a smokeless fuel is desirable. The oven coke is usually in large columnar masses of a close texture and quite hard. It has a dead gray-black color and is not susceptible of polish. It is principally used in furnaces requiring a blast, although limited quantities of it have been used in domestic heating, for which purpose it must be broken up much finer than its usual size. Petroleum coke is generally in large irregular lumps, perforated with cavities of greater or less size, the interiors of which are usually quite smooth and shining. Its color is blacker than that of gas or oven coke, and its hardness intermediate. It is used principally for making electric carbons, although considerable quantities are used for fuel.

With the exception of gas-coke little use is made of this fuel for steaming. In all cases plenty of air is needed to keep up the combustion, which is also a drawback for steaming purposes. For metallurgical furnaces, however, it is almost the ideal fuel, giving an intense reducing heat at just the part of the furnace where it is most needed. Oven coke has been used in cupolas and blast furnaces for years. It is superior to anthracite, as it has no tendency to splinter and crack with the heat, and bears its burden very well.

Coke is essentially carbon, and the mineral portions of the coal from which it is made. It also contains small quantities of hydrogen and nitrogen. The percentage of these, however, is so low that the calculated and observed heat-units are usually within the limits of error shown in the following table:

Name.	C.	H.	N.	Loss.	Calories Observed.	Calories Calculated.	Authority.
Saarbruck.....	98.04	0.73	....	1.23	8200	8229	Bunte
Petroleum coke..	98.05	0.50	0.25	1.20	8057	8151	Mahler
Graphite.....	98.98	0.02	....	....	7901	8054	Berthelot

COMPARATIVE ANALYSES AND HEATING VALUE OF GAS-COAL AND COKE

(Bulletin No. 6, U. S. Bureau of Mines, 1911)

Kind of Coal.	Coal.						Coke.					
	Moisture.	Ash.	Volatile Matter.	Fixed Carbon.	Sulphur.	Heating Value B.T.U.	Moisture.	Ash.	Volatile Matter.	Fixed Carbon.	Sulphur.	Heating Value B.T.U.
PITTSBURGH:												
As received	1.92	6.41	32.82	58.85	1.12	14,026	8.54	11.46	0.97	79.03	0.84	11,552
Dry	.....	6.54	33.46	60.00	1.14	14,301	.....	12.53	1.06	86.41	0.92	12,631
PITTSBURGH:												
As received	2.18	7.53	32.96	57.33	1.43	13,815	18.23	9.00	1.22	71.55	0.69	10,543
Dry	.....	7.70	33.70	58.60	1.46	14,123	.....	11.01	1.49	87.50	0.84	12,893
ALABAMA:												
As received	2.71	4.29	29.13	63.87	0.50	13,990	.....	.....	.....	.....	.....	.....
Dry	.....	4.41	29.94	65.65	0.51	14,380	.....	11.40	1.59	81.01	0 52	12,883
COLORADO:												
As received	7.17	14.55	32.36	45.92	1.00	10,953	21.31	19.93	1.40	57.28	0.68	8,417
Dry	.....	15.67	34.86	49.47	1.08	11,799	.....	25.35	1.78	72.87	0.87	10,706
COLORADO:												
As received	0.71	18.32	24.14	56.83	0.57	12,436	23.09	15.89	0.73	60.29	0.38	8,998
Dry	.....	18.45	24.31	57.24	0.58	12,524	.....	20.66	0.95	78.39	0.49	11,700
ILLINOIS:												
As received	4.66	7.19	34.44	53.71	1.96	12,919	.....	.....	.....	.....	.....	.....
Dry	.....	7.54	36.13	56.33	2.06	13,550	.....	12.30	2.22	85.48	2.08	12,427
KENTUCKY:												
As received	2.46	6.25	31.18	60.11	0.43	13,885	12.43	10.09	0.92	76.56	0.36	11,210
Dry	.....	6.41	31.97	61.62	0.44	14,234	.....	11.52	1.05	87.43	0.41	12,802

COMPARATIVE ANALYSES AND HEATING VALUE OF GAS-COAL AND COKE—*Continued*

Kind of Coal.	Coal.						Coke.					
	Moisture.	Ash.	Volatile Matter.	Fixed Carbon.	Sulphur.	Heating Value B.T.U.	Moisture.	Ash.	Volatile Matter.	Fixed Carbon.	Sulphur.	Heating Value B.T.U.
KENTUCKY:												
As received....	3.17	3.76	32.40	60.67	0.45	14,200	.....	.....	.....	.....	.....	.....
Dry.....	.....	3.88	33.46	62.66	0.46	14,665	.....	10.01	0.39	89.60	0.43	13,003
MICHIGAN:												
As received....	9.28	5.35	31.67	53.70	0.98	12,456	.....	.....	.....	.....	.....	.....
Dry.....	.....	5.90	34.91	59.19	1.08	13,730	.....	5.79	2.20	92.01	0.91	13,495
NEW MEXICO:												
As received....	2.23	15.10	31.42	51.25	0.67	12,438	22.30	17.56	0.58	59.56	0.31	8,681
Dry.....	.....	15.44	32.14	52.42	0.69	12,722	.....	22.60	0.75	76.65	0.40	11,173
TENNESSEE:												
As received....	3.13	2.15	34.99	59.73	0.72	14,245	26.80	4.45	0.86	67.89	0.51	10,094
Dry.....	.....	2.22	36.12	61.66	0.74	14,706	.....	6.08	1.17	92.75	0.70	13,790
WEST VIRGINIA:												
As received....	1.28	5.57	30.65	62.50	1.53	14,531	22.59	9.37	0.38	67.66	0.66	9,855
Dry.....	.....	5.64	31.05	63.31	1.55	14,720	.....	12.10	0.49	87.41	0.85	12,731
WEST VIRGINIA:												
As received....	1.27	6.83	29.02	62.88	1.18	14,344	.....	.....	.....	.....	.....	.....
Dry.....	.....	6.92	29.39	63.69	1.20	14,530	.....	13.26	0.73	86.01	1.19	12,591
WYOMING:												
As received....	22.56	5.81	32.26	39.37	0.36	9,592	16.25	11.49	1.06	71.20	0.34	10,447
Dry.....	.....	7.80	41.66	50.84	0.46	12,386	.....	13.72	1.27	85.01	0.41	12,474

The cokes listed in the above table were the residue from the manufacture of illuminating gas. The coke as drawn was quenched and allowed to stand in the buggy for three days, when the moisture was determined. As the coke had to be drowned to prevent it catching fire, the moisture figures have but little value in showing what moisture coke will retain under normal conditions. The analysis of the dry coke represents the coke as drawn from the retort and before quenching.

OVEN COKES

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
AMERICA												
Connellsville, Pa	89.58	0.46	....	....	....	....	0.81	0.03	9.11	7895	14,211	Anonymous
Coketon, Pa	86.58	1.26	....	....	....	....	1.49	....	10.67	8015	14,427	"
Beaver Falls, Pa	84.73	0.63	....	....	....	....	1.99	0.01	12.64	8039	14,471	"
Clarion Co., Pa	88.36	1.11	....	....	....	....	1.08	0.23	9.23	8022	14,440	"
Bloss, Pa	81.92	0.57	....	....	....	....	0.90	0.78	7.95	7983	14,369	"
Coalbury, Pa	84.67	0.68	....	....	....	....	1.87	0.13	12.63	7897	14,210	McCreath, analyst]
Connellsville, Pa	89.51	0.88	....	....	....	....	0.71	0.70	8.83	7911	12,240	Wedding
Connellsville, Pa	87.46	0.01	....	....	....	....	0.69	0.49	11.32	8070	14,526	Morrell
Connellsville, Pa. (average of 3)	88.96	....	....	....	....	....	0.81	....	9.74	8020	14,436	"
Dade, Pa	75.94	0.09	....	....	....	....	0.67	0.54	21.75	7953	14,315	McCreath
Daisy, Pa	79.83	1.05	....	....	....	....	2.13	1.22	15.75	7731	13,883	"
Etna, Pa	85.45	1.16	....	....	....	....	1.45	0.86	11.08	7896	14,212	"
Fairmont, Pa	85.78	0.62	....	....	....	....	2.11	0.30	11.46	8034	14,464	Anonymous
Irwin, Pa	88.24	1.38	....	....	....	....	0.96	....	9.41	8026	14,447	"
Jefferson Co., Pa	88.95	1.42	....	....	....	....	0.90	0.78	7.95	7983	14,369	"
Kittanning, Pa	87.22	....	....	....	....	....	1.23	....	11.43	8046	14,483	"
Pratt, Pa	88.87	1.58	....	....	....	....	1.18	1.92	8.99	7946	14,300	McCreath
Pratt, Pa	86.48	1.13	....	....	....	....	1.05	0.13	11.21	7937	14,286	"
St. Bernard No. 9, Pa	87.27	0.61	....	....	....	....	2.21	....	12.11	8075	14,543	Morrell
St. Bernard No. 11, Pa	90.69	0.34	....	....	....	....	2.37	....	8.96	7995	14,340	"
Seymour, Pa	90.65	0.63	....	....	....	....	0.85	0.22	7.65	8036	14,468	Anonymous
Snow Shoe Co., Pa	82.63	2.95	....	....	....	....	1.10	0.99	12.33	8017	14,431	"
Fairmont, W. Va	91.08	1.85	....	....	....	....	0.67	0.24	6.83	8025	14,445	Wedding
Flat Top, W. Va	92.55	0.76	....	....	....	....	0.60	0.35	5.75	8011	14,420	"
New River, W. Va. (av. of 8)	92.38	....	....	....	....	....	0.56	....	7.21	8015	14,427	Proctor
Pocahontas, W. Va	91.68	0.52	....	....	....	....	0.75	1.11	7.57	8090	14,562	McCreath
Pocahontas, W. Va. (av. of 3)	92.53	....	....	....	....	....	0.60	....	5.74	7988	14,378	Proctor
Pocahontas, W. Va	91.43	1.27	....	....	....	....	0.51	0.70	6.09	8006	14,411	Anonymous
Pocahontas, W. Va	92.82	0.66	....	....	....	....	0.55	0.66	4.91	8032	14,457	"

OVEN COKES—*Continued*

Name or Location.	Carbon.			Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.							Calories.	B.T.U.	
AMERICA—*Continued*												
Pocahontas, W. Va	92.55	0.76	....	....	....	....	0.60	0.35	5.75	8011	14,418	Anonymous
Pocahontas, W. Va	92.58	0.49	....	....	....	....	0.68	0.29	6.05	8000	14,400	"
Pineville, W. Va	94.66	0.04	....	....	....	....	0.69	1.14	3.57	8006	14,128	Morrell
Big Stone Gap, Ky. (av. of 7)	93.23	....	....	....	....	....	0.75	....	5.69	8044	14,479	Proctor
De Bardeleben, Ala. (48 hours)	86.00	0.70	....	....	....	....	1.23	0.40	12.90	8019	14,435	Phillips
De Bardeleben, Ala. (72 hours)	87.25	0.90	....	....	....	....	0.99	0.05	11.80	7998	14,397	"
Birmingham, Ala. (av. of 4)	87.29	....	....	....	....	....	1.19	....	10.54	7940	14,290	Proctor
Chattanooga, Tenn. (av. of 4)	80.51	....	....	....	....	....	1.59	....	16.34	7832	14,097	"
FRANCE												
Anthracite	.....	....	91.04	0.68	2.15		....	0.23	5.90	8036	14,465	Mahler
Antin	.....	....	91.58	0.63	1.58		....	....	3.20	8004	14,407	"
Commentry	.....	....	92.73	0.44	2.63		....	....	4.20	8001	14,402	"
Grand Combe	.....	....	89.27	0.21	2.22		....	0.59	7.80	7920	14,256	"
Mons	.....	....	92.34	0 34	....		....	....	....	7936	14,284	De Marcilly
ENGLAND												
Best, Durham	.....	....	93.15	0.72	0.90	1.28	0.65	....	3.95	8101	14,582	Kubale
Average, Durham	.....	....	84.92	4.53	6.66	1.96	0.81	....	2.28	7899	14,218	"
Busty, Durham (upper layer)	.....	....	81.22	4.70	9.45	....	1.83	0.85	3.28	7911	14,240	"
Busty, Durham (lower layer)	.....	....	78.46	4.42	8.82	....	1.00	0.99	6.17	7959	14,326	"
Brockwell, Durham	.....	....	83.40	4.40	7.18	....	0.81	0.99	3.50	7811	14,060	"
Hamsteels	.....	....	92.55	....	....	....	0.84	0.21	6.36	8011	14,420	"
Consett	.....	....	91.88	....	....	....	1.21	0.37	6.91	8020	14,436	"
Whiteworth	.....	....	91.56	....	....	....	....	0.54	6.69	8002	14,404	"
South Braucepeth	.....	....	93.43	....	....	....	0.91	0.36	5.30	8005	14,409	"
NEW SOUTH WALES												
Mount Pleasant	85.85	0.50	....	....	....	....	....	0.20	13.45	8043	14,477	Murgaye

GAS COKES

Name or Location.	Carbon.			Hydrogen.	Oxygen and Nitrogen.	Sulphur.	Water.	Ash.	Heat Units of Combustible.		Authority.
	Fixed.	Volatile.	Total.						Calories.	B.T.U.	
GERMANY											
Sulkov, Bohemia	87.23	1.76	....	0.53	2.96	1.39	0.90	9.62	7865	14,157	Bunte
Pankraz, Bohemia	83.74	2.47	....	0.83	3.84	2.31	0.81	11.48	7790	14,022	"
Consolidation, Ruhr	90.58	0.21	....	0.70	4.04	1.79	0.87	7.42	7785	13,913	"
Rhone-Elbe and Alma, Ruhr	89.75	2.04	....	0.81	4.80	1.71	0.88	6.50	7716	13,889	"
Ewald, Ruhr	83.98	2.51	....	0.90	3.74	2.53	1.17	11.18	7781	14,006	"
Bonifacius, Ruhr	84.56	3.17	....	1.07	3.61	1.53	1.02	10.74	7819	14,074	"
Camphausen, Saar	85.14	2.80	....	1.00	2.60	1.79	1.43	10.27	7900	14,226	"
Heintz	91.78	0.74	....	0.78	2.85	0.96	0.81	6.52	7862	14,152	"
United Glückhilf, Lower Silesia	85.54	1.34	....	0.92	2.34	1.52	1.24	11.60	8022	14,440	"
Deutschland, Upper Silesia	90.62	2.46	....	0.75	3.13	3.20	0.96	3.72	7826	14,087	"
Königin Louise, Upper Silesia	87.93	0.93	....	0.54	2.01	0.96	3.73	6.41	7938	14,288	"
Saarbruck	98.04	0.73	....	....	....	....	....	....	8200	14,760	"
Petroleum coke	98.05	0.50	....	....	....	....	....	....	8057	14,503	Mahler
Bohemian coke	98.81	1.19	....	....	....	....	....	....	8290	14,922	Bunte

COKE BREEZE

Coke breeze has been used in England as a gas producer fuel for making gas in firing brick kilns. The coke ran about 10 per cent ash, and in size was about as follows: through 1/2-in. mesh, 40 per cent; between 1/2 and 1/4 in., 19 per cent; between 1/4 and 1/8, in. 14 per cent; less than 1/8 in., 27 per cent.

The accompanying table gives the analysis and calorific value of the coke breeze as determined by the U. S. Bureau of Mines and reported in Technical Paper 123.

ANALYSIS AND CALORIFIC VALUE OF COKE BREEZE

Condition of Sample.	Proximate Analysis.				Sulphur.	Ultimate Analysis.				Air Drying Loss.	Calorific Value.	
	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.		Hydrogen.	Carbon.	Nitrogen.	Oxygen.		Calories.	B.T.U.
As received	10.77	4.92	72.26	12.05	0.79	2.37	73.16	0.92	10.71	10.1	6200	11,160
Air dried	0.73	5.47	80.40	13.40	.88	1.39	81.39	1.02	1.92	....	6897	12,414
Moisture free	.....	5.51	80.99	13.50	.89	1.31	81.99	1.03	1.28	....	6948	12,506
Moisture and ash free	.....	6.37	93.63	.....	1.03	1.51	94.79	1.19	1.48	....	8033	14,459

WOOD CHARCOAL

Wood charcoal, made by the destructive distillation of wood, always contains quantities of hydrocarbons which have resisted the action of heat. So-called forest charcoal, made by burning wood in heaps, contains more hydrocarbons than charcoal made by distilling wood in retorts.

The heat of combustion of charcoal is quite variable. According to Berthier* commercial wood charcoal contains 10 per cent of volatile matters and 2 per cent of ash (carbon 80 to 90, hydrogen 1.5–4).

Pure wood charcoal was first tested calorimetrically by Favre and Silbermann, and since then by several experimenters. To obtain it pure it was calcined strongly and treated with chlorine to remove all traces of hydrogen. In this state wood-charcoal produces under constant pressure 8080 calories, according to Favre and Silbermann; with constant volume Berthelot and Petit obtained 8137 calories.

* Traité des essais par la voie sèche, Vol. I, p. 286.

Several years ago Berthier pointed out that half-burned charcoal, *charbon roux* or *Rothkohle*, was superior in combustible content to that perfectly burned. Sauvage has confirmed this, and gives the following results:

100 Lb. of Wood charred for...	3 Hours.	4 Hours.	5 Hours.	5½ Hours.	6½ Hours.	Mound Charcoal.
Weighed.....	65.4 lb.	53.0 lb.	47.0 lb.	41.5 lb.	39.1 lb.	17.2 lb.
100 cu.ft. measured	86 cu.ft.	76 cu.ft.	58 cu.ft.	55 cu.ft.	52 cu.ft.	33 cu.ft.

and 1 cu. ft. wood contained of combustible matter		908 parts.
1 cu. ft. 3 hours' heating		883
1 cu. ft. 4 "	"	904
1 cu. ft. 5 "	"	1133
1 cu. ft. 5½ "	"	1091
1 cu. ft. 6½ "	"	1136
1 cu. ft. charcoal		1069

The amount of combustible matter does not increase after 5 hours' heating, and a continuance of the heat beyond that period diminishes it.

The principal use of charcoal is in iron blast-furnaces, where it has been used for years, and produces the highest grades of iron, being free from sulphur and phosphorus. The amount of iron produced by means of it, however, is insignificant in comparison with the amount produced in coke blast-furnaces. A small amount is used in private dwellings and hotels for heating and cooking. For boiler-heating it has been used only experimentally.

Scheurer-Kestner and Meunier-Dollfus experimented with it in boiler-heating and found very little combustible gas in the the products. Beech charcoal was used, and an evaporative effect of 7.62 lb. of water was obtained. The waste gases contained:

	Per Cent.
Carbon dioxide	11.16
Carbon monoxide	0.37
Oxygen	8.72
Nitrogen	79.75
	100.00

Brix, using wood and peat charcoal, obtained the following results:

Wood charcoal..... 7.55 lb. evaporated.
Peat charcoal.....6.85 " "

Schwackhöfer burned charcoal from hard and soft wood in his calorimeter and obtained (constant volume) 7140 calories for the soft charcoal and 7071 calories for the hard. The charcoal in both cases was the ordinary unpurified charcoal as sold.

WOOD

Wood consists of a compact tissue more or less hard, formed of cellulose and a so-called incrusting substance. Wood contains besides, small quantities of mineral matter and hygroscopic water varying from 30 to 50 per cent, according to dryness. Air-dried it contains about 20 per cent of water, which it gives up easily on exposure to a heat of 240 deg. Fahr.

The following table by Eugene Chevandier gives the composition of different varieties of wood:

ANALYSIS OF WOODS

Woods.	Composition.				
	Carbon.	Hydrogen.	Oyxgen.	Nitrogen.	Ash.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Beech	49.36	6.01	42.69	0.91	1.06
Oak	49.64	5.92	41.16	1.29	1.97
Birch	50.20	6.20	41.62	1.15	0.81
Poplar	49.37	6.21	41.60	0.96	1.86
Willow	49.96	5.96	39.56	0.96	3.37
Average	49.70	6.06	41.30	1.05	1.80

Regarding wood from its ultimate composition, we may consider it as a hydrate of carbon, that is, as carbon united to water, the proportion of hydrogen and oxygen being nearly the same as in water. But regarded from its proximate composition, it is entirely different. What has been said of soft coal can be repeated for wood; that, those having a similar ultimate composition behave differently in distillation in a closed retort and produce very different proportions of carbon (as charcoal), hydrocarbons,

liquid or gaseous, acid products, resin, and tar. The heat of combustion differs also.

Hard wood gives less heat than soft wood. According to Gottlieb's experiments, pine-wood has a heat value of 5000 calories while oak gave only 4620 calories. Mahler's experiments confirm a difference in favor of pine, but in less proportion.

Two determinations made by Mahler are (cinders and water deducted):

	Fir.	Oak.
Carbon	51.08	50.43
Hydrogen	6.12	5.88
Oxygen with trace of nitrogen	42.90	43.69
	100.00	100.00
Heat of combustion	4828	4689

Gottlieb obtained the following figures, using a calorimeter of constant pressure, in which he burned 2 grams of wood in the space of two or three minutes. The composition of the gas produced was not determined; he was satisfied that he had perfect combustion, and his figures do not appear very far from the truth. For cellulose he obtained 4155 calories.

GOTTLIEB'S DETERMINATION OF CALORIFIC POWER OF WOOD

Wood.	C.	H.	N.	O.	Ash.	Calories.	B.T.U.
Oak	50.16	6.02	0.09	43.36	0.37	4620	8316
Ash	49.18	6.27	0.07	43.91	0.57	4711	8480
Elm	48.99	6.20	0.06	44.25	0.50	4728	8510
Beech	49.06	6.11	0.09	44.17	0.57	4774	8591
Birch	48.88	6.06	0.10	44.67	0.29	4771	8586
Fir	50.36	5.92	0.05	43.39	0.28	5035	9063
Pine	50.31	6.20	0.04	43.08	0.37	5085	9153

Gottlieb's results are 69 calories less than Mahler's for oak and 207 more for fir.

The relative heating value of coal and wood is shown by the table below which is quoted in a number of text-books. The authority and quality of coal are not given. The wood is assumed to be thoroughly air-dried, and the weight of wood given is the weight of one cord.

RELATIVE HEATING VALUE OF WOOD AND COAL

Hickory or hard maple	4500	lb.	equal to	1800	lb.	coal.	(Others give	2000)
White oak	3850	"	"	1540	"		("	1715)
Beech, red and black oak	3250	"	"	1300	"		("	1450)
Poplar, chestnut, and elm	2350	"	"	940	"		("	1050)
The average pine	2000	"	"	800	"		("	925)

The table shows that $2\frac{1}{4}$ lb. of dry wood are about equal to 1 lb. average quality of soft coal and that the fuel value of the same weight of different woods is very nearly the same—that is, a pound of hickory is worth no more for fuel than a pound of pine, assuming both to be dry. This is at variance with Mahler's results quoted above. It is important that the wood be dry, as each 10 per cent of water or moisture in wood will detract about 12 per cent from its value as fuel.

Taking an average wood of the analysis, perfectly dry, C, 50; H, 6; O, 42; N and ash, 2, its total heating value, by Dulong's formula, is 7765 B.T.U. per pound. If the wood contains 25 per cent of moisture the analysis of the moist wood is C, 37.5; H, 4.5; O, 31.5; N and ash, 1.5, and its total heating value is 75 per cent of 7765, or 5824 B.T.U. per pound. To obtain the "available" heating value we subtract the loss of heat in the steam formed from the water and the hydrogen in the wood, as calculated by formula*. Taking the temperature of the air supply at 62 deg. Fahr. and that of the escaping chimney-gases at 462 deg. Fahr., this loss is 810 B.T.U., which subtracted from 5824 gives 5014 B.T.U. per pound as the available heating value.

In burning wood for steaming the fire is easily controlled; combustion is more complete; the products of combustion contain only very small quantities of unburned gases; and the ashes are generally free from carbon. The countries using wood for this purpose are growing less in number yearly, on account of improvement in transportation and the discovery of new coal seams; petroleum oils for fuel have also become more common, especially in Russia, the United States, and Canada.

*B.T.U. lost due to hydrogen and moisture

$$=(9H+W)\times[(212-t)+970+0.48(T_c-212)]$$

in which H is the percentage of hydrogen, W the water in 1 lb. of fuel, t the atmospheric temperature and T_c the temperature of the chimney gases, in degrees Fahr.

RELATIVE VALUE OF VARIOUS WOODS

Wood.	Specific Gravity.	Pounds in One Cord.	Percentage Charcoal.	Specific Gravity of Charcoal.	Pounds of Charcoal in a Bushel.	Relative Value of Wood.
Hickory, shell bark	1.000	4469	26.22	0.625	32.89	1.00
Oak, chestnut	0.885	3955	22.75	0.481	25.31	0.86
Oak, white	0.885	3821	21.62	0.401	21.10	0.81
Ash, white	0.772	3450	25.74	0.447	28.78	0.77
Dogwood	0.815	3643	21.00	0.550	29.94	0.75
Oak, black	0.728	3254	23.80	0.387	20.36	0.71
Oak, red	0.728	3254	22.43	0.400	21.05	0.69
Beech, white	0.724	3236	19.62	0.518	27.26	0.65
Walnut, black	0.681	3044	22.56	0.418	22.00	0.65
Maple, hard (sugar)	0.644	2878	21.43	0.431	22.68	0.60
Cedar, red	0.565	2525	24.72	0.238	12.52	0.56
Magnolia	0.605	2704	21.59	0.406	21.36	0.56
Maple, soft	0.597	2668	20.04	0.370	19.47	0.54
Pine, yellow	0.551	2463	23.73	0.333	17.52	0.54
Sycamore	0.535	2391	23.60	0.274	19.68	0.52
Butternut	0.567	2534	20.79	0.237	12.47	0.51
Pine, New Jersey	0.478	2137	24.88	0.385	20.26	0.48
Pine, pitch	0.426	1904	26.76	0.298	15.68	0.43
Pine, white	0.418	1868	24.35	0.293	15.42	0.42
Poplar, Lombardy	0.397	1774	25.00	0.245	12.85	0.40
Chestnut	0.552	2333	25.29	0.379	19.74	0.52
Poplar, yellow	0.563	2516	21.81	0.383	20.15	0.52

WOOD REFUSE

Wood refuse is used as a fuel for gas producers at the plant of the Southern Cotton Oil Co., Gretna, La. The refuse used is known as "cypress hog," consisting of about 50 per cent sawdust and 50 per cent chips, and containing about 30 to 35 per cent moisture. The plant was described in a paper read by Charles E. Snypp before the Louisiana Engineering Society, May 13, 1912. The gas obtained from the "cypress hog" ran from 130 to 135 B.T.U. per cubic foot, while gas from "pine hog" had a calorific value of 161.4 B.T.U. per cubic foot (average of 11 analyses). The calorific values of the cypress and pine respectively were 5540 B.T.U. and 7605 B.T.U. per pound.

MISCELLANEOUS SOLID FUELS

Straw.—Clark* gives the following analysis of wheat and barley straw, the two varying less than one per cent: Carbon, 36; hydrogen, 5; oxygen, 38; nitrogen, 0.50; ash, 4.75; water, 15.75. According to Dulong's formula, the calorific value of this

* Steam Engine, Vol. I, p. 62.

ANALYSES AND HEATING VALUE OF WOOD

Name.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.	Water.	Calories.	B.T.U.	Authority.
Ash	49.18	6.27	43.91	0.07	0.57	.....	4711	8,480	Gottlieb
Beech	49.06	6.11	44.17	0.09	0.57	.....	4774	8,591	"
Birch	48.88	6.06	44.67	0.10	0.29	.....	4771	8,586	"
Elm	48.89	6.20	44.25	0.06	0.50	.....	4728	8,510	"
Fir	50.36	5.92	43.39	0.05	0.28	.....	5035	9,063	"
Oak	50.16	6.02	43.36	0.09	0.37	.....	4620	8,316	"
Pine	50.31	6.20	43.08	0.04	0.37	.....	5085	9,153	"
Norway pine	47.37	5.58	39.78	....	0.34	6.94	4828	8,690	Mahler
Oak from Lorraine	46.59	5.43	40.34	....	0.75	6.93	4689	8,440	"
Pine-knot, Wyoming	.....	....	.....	....	.....	.....	6035	10,863	Slosson
Tan bark	.....	....	.....	....	15.0	.....	3389	6,100	Peclet
" "	.....	....	.....	....	.....	30.0	2380	4,284	"
Straw, wheat, Russia	.....	....	.....	....	.....	6.20	5770	10,386	Eng. Mechanics, February, 1893
" " (dry)	46.1	5.6	43.7	0.42	4.10	0.00	6290	11,322	
" "	.....	....	.....	....	.....	10.00	5448	9,806	"
Straw, buckwheat (dry)	.....	....	.....	....	.....	.....	5590	10,068	"
" flax (dry)	.....	....	.....	....	.....	.....	6750	12,150	"

straw would be 5411 B.T.U. Russian wheat straw,* dried at 230 deg. Fahr., of composition, Carbon, 46.1; hydrogen, 5.6; nitrogen, 0.42; oxygen, 43.7; ash, 4.1, had a calorific value of 6290 B.T.U. The same straw containing 10 per cent of water had a heating value of 5448 B.T.U. Buckwheat straw, dry, is given as having a heating value of 5590 B.T.U., while dry flax straw is given as 6750 B.T.U.

Bagasse.—Bagasse is refuse sugar-cane, the juice having been extracted. Prof. L. A. Becuel† says concerning bagasse: "With tropical cane containing 12.5 per cent woody fiber, a juice containing 16.13 per cent solids, and 83.87 per cent water, bagasse of, say, 66 per cent and 72 per cent mill extraction would have the following percentage composition:

	Woody Fiber.	Combustible Salts.	Water.
66 per cent bagasse	37	10	53
72 per cent bagasse	45	9	46

"Assuming that the woody fiber contains 51 per cent carbon, the sugar and other combustible matters an average of 42.1 per cent, and that 12,906 B.T.U. are generated for every pound of carbon consumed, the 66 per cent bagasse is capable of generating 2978 B.T.U. per pound as against 3452, or a difference of 474 B.T.U. in favor of the 72 per cent bagasse.

"Assuming the temperature of the waste gases to be 450 deg. Fahr., that of the surrounding atmosphere and water in the bagasse at 86 deg. Fahr., and the quantity of air necessary for the combustion of 1 lb. of carbon at 24 lb., the lost heat will be as follows: In the waste gases, heating air from 86 to 450 deg. Fahr., and in vaporizing the moisture, etc., the 66 per cent bagasse will require 1125, and the 72 per cent bagasse 1161 B.T.U.

"Subtracting these quantities from the above, we find that the 66 per cent bagasse will produce 1853 available B.T.U., or nearly 38 per cent less than the 72 per cent bagasse, which gives 2990 B.T.U."

* Eng. Mechanics, Feb., 1893, p. 55.

† Paper read before Louisiana Sugar Chemists' Association, 1892.

Samuel Vickess in *The Engineer*, Chicago, April 1, 1903, writes:

The value of bagasse as a fuel depends upon the amount of woody fiber it contains, and the amount of combustible matter (sucrose, glucose, and gums), held in the liquid it retains. One hundred pounds cane with triple crushing gives 76 lb. juice, and 24 lb. bagasse, which consists of 12 lb. fiber and 12 lb. juice. The 12 lb. of juice contains 16 per cent or 1.92 lb. sucrose, 0.5 per cent or 0.06 lb. glucose, 2.5 per cent other organic matter and 1 per cent or 0.12 lb. ash, making a total of 20 per cent or 2.4 lb. of solid matter, and 80 per cent or 9.6 lb. of water. Reducing these figures to quantities corresponding to 1 lb. of bagasse, and multiplying by the heating values of the several substances as given by Stohlmann, we find the heating value of the combustible in 1 lb. of bagasse as follows:

0.5	lb. fiber	×7461 =	3730	B.T.U.
0.08	lb. sucrose	×6957 =	557	"
0.0025	lb. glucose	×6646 =	17	"
0.0125	lb. org. matter	×7461 =	93	"
			4397	
0.4	lb. water			
0.005	lb. ash			
1.0000				

This 4397 B.T.U. is the gross heating value, which would be obtained in a calorimeter in which the products of combustion were cooled to the temperature of the atmosphere. To find approximately the heat available for generating steam in a boiler we may assume that 10 lb. of air is used in burning each pound of bagasse, that the atmospheric temperature is 82 deg. Fahr. and the flue gas temperature 462 deg. Fahr., and that in addition to the 0.4 lb. of water per pound bagasse one-half of the remaining 0.6 lb. is oxygen and hydrogen in proportions which form water, making 0.7 lb. water which escapes in the flue gas as superheated steam. The heat lost in the flue gases per pound of bagasse is

$$[10\times0.24\times(462-82)+0.7(212-82)+970+0.5\ (462-212)]$$
$$=1770 \text{ B.T.U.},$$

which subtracted from 4397 leaves 2627 B.T.U. as the net or available heating value, which is equivalent to an evaporation of 2.7 lb. of water from and at 212 deg. Fahr. In practice 1 lb. of such green bagasse evaporates 2 to 2¼ lb. from feed water at 100 deg. Fahr. into steam at 90 lb. pressure. This is equivalent to from 2.31 to 2.59 lb. from and at 212 deg. Fahr.

Wet Tan Bark. Tan bark is used as fuel after having been used for the tanning of leather, the spent tan consisting of the fibrous portion of the oak bark. Peclet says that the calorific value of perfectly dry tan with 15 per cent of ash is 6100 B.T.U. and that tan containing 30 per cent of water, which is the normal state of dryness, has a heating value of 4284 B.T.U. David M. Meyers (Trans. A.S.M.E. 1909) gives the average heating value of dry hemlock tan as 9504 B.T.U. By Dulong's formula the heating value would be 8152 B.T.U., the composition of the dry tan cited by Mr. Meyers being ash, 1.42, carbon, 51.80, hydrogen, 6.04, oxygen, 40.74.

When wet tan bark is burned in the boiler furnace, the moisture in it is converted into superheated steam and this escaping with the chimney gases carries away a large amount of heat. The amount of heat so lost depends upon the amount of moisture present in the tan, and the table herewith shows the effect of varying quantities of moisture both upon the heating value and the evaporative effect of the wet tan bark.

CALORIFIC VALUE OF TAN WITH VARIOUS PERCENTAGES OF MOISTURE *

Moisture.	B.T.U. per Lb. Wet Tan.	Losses of Heat Due to			Net Heat Value, B.T.U.	Efficiency, per Cent.	Lb. Evap. per Lb. Wet Tan.
		Moisture.	H in Fuel.	Heating Air.			
0.20	6336	261	564	1446	4065	64.2	4.19
0.30	5544	392	493	1266	3393	61.2	3.50
0.40	4752	522	423	1085	2772	57.3	2.81
0.50	3960	653	352	904	2051	51.8	2.11
0.60	3168	784	282	723	1379	43.5	1.42
0.70	2376	914	211	542	709	29.8	0.73
0.80	1584	1045	141	362	36	2.5	0.03

* Composition of dry tan bark assumed to be C 0.50; H 0.06; O 0.40; N and Ash 0.04. Heating value by Dulong's formula 7920 B.T.U. per pound. Chimney gases are assumed to escape at 600 deg. Fahr.

CHAPTER VII

LIQUID FUELS

Of the many oils capable of use as fuel, only those of mineral origin are used. The vegetable oils are too costly and possess no advantage over the mineral oils. The mineral oils comprehend the liquid hydrocarbons extracted from bituminous schist or coal and its congeners by distillation, as well as the oils which exist already formed in the earth, and called by the special name of *petroleum*. While the former are seldom employed in heating, petroleum has become an important fuel in the countries which produce it.

Petroleum is a mixture of liquid hydrocarbons, which exist in several series as shown by the following table by Johnson and Huntley.*

DIVISION OF THE PETROLEUM SERIES

Generalized Formula.	Name of Series.	Most Abundant in Oil From
C_nH_{2n+2}	Paraffin	Pennsylvania and in natural gas
C_nH_{2n}	Olefin and polymethylene	Russia, California and Cuba
C_nH_{2n-2}	Acetylene	Texas, Louisiana and Lima, Ind.
C_nH_{2n-4}	Rare	Lima, Indiana, and California
C_nH_{2n-6}	Benzene	Nearly all fields in small quantities
C_nH_{2n-8}	Rare	California
C_nH_{2n-10}	Rare	"
C_nH_{2n-12}	Includes naphthalene $C_{10}H_8$	California and Cuba

Crude petroleum, subjected to fractional distillation, gives the lighter fuels of commerce, such as benzine, gasoline, kerosene, etc. The table below, also from Johnson and Huntley, shows how the paraffin series may be broken up to form the more familiar commodities.

* Oil and Gas Production, p. 1.

DIVISION OF THE PARAFFIN SERIES OF PETROLEUM

Name.	Chemical Symbol.	Boiling-point, Degrees F.	Gravity Baumé at 68 Deg. F.	Commercial Name.
Methane	CH_4	−256.5	.....	Natural gas
Ethane	C_2H_6	−135.4	.....	Natural gas
Propane	C_3H_8	− 49.0	.....	Gasol
Butane	C_4H_{10}	+ 33.8	.....	Gasol
Pentane	C_5H_{12}	+100.4	93 at 57	Gasoline
Hexane	C_6H_{14}	+158.0	83	Gasoline
Heptane	C_7H_{16}	+208.4	75	Gasoline
Octane	C_8H_{18}	+257.0	69	Gasoline
Nonane	C_9H_{20}	+298.3	65	Kerosene
Decane	$C_{10}H_{22}$	+334.3	62	Kerosene

Gasoline may be extracted from the casing head gas coming from oil wells, by the condensation of the propane and butane in the gas. Low-grade naphtha is sometimes blended with gas-gasoline to form a commercial gasoline whose specific gravity is the same as that obtained by distillation in the refinery, but which contains varying quantities of the lighter constituents to compensate for the heavy hydrocarbons.

Petroleum is found in vast quantities in the United States, Mexico and Russia. Canada, Roumania, Burmah, Australia, Peru, India, Java, and other localities have produced smaller quantities.

Among the first to use liquid fuel, and the first to bring its use to a state of perfection, were the Russians. For years they have used it exclusively in their locomotives and in many marine engines. At first the crude oil was used, but afterwards astatki, or residuum from the first distillation. Special burners were invented in large numbers, and now its use is a settled fact and increasing.

Thomas Urquhart there obtained an efficiency of 82 per cent of the theoretical heating value in experiments on the Russian railways. He fed the petroleum to the furnace by means of a spray-injector driven by steam. An induced current of air was carried in around the injector-nozzle, and additional air was supplied at the bottom of the furnace.

Mr. Urquhart (Proc. Inst. M.E., Jan., 1889) gives the following table comparing the theoretical heating effect of petroleum, as compared with that of coal as determined by Favre and Silbermann.

COMPARATIVE HEATING VALUE OF PETROLEUM AND OTHER FUELS

Fuel.	Specific Gravity at 32 Deg. F., Water = 1.000.	Chem. Comp.			Heating Power, British Thermal Units.	Theoret. Evap., Lbs. Water per Lb. Fuel, from and at 212 deg. F.
		C, Per Cent.	H, Per Cent.	O, Per Cent.		
Penna. heavy crude oil..	0.886	84.9	13.7	1.4	20,736	21.48
Caucasian light crude oil	0.884	86.3	13.6	0.1	22,027	22.70
Caucasian heavy "	0.938	86.6	12.3	1.1	20,138	20.85
Russian naphtha refuse .	0.928	87.1	11.7	1.2	19,832	20.53
Good English coal, mean of 98 samples.....	1.380	80.0	5.0	8.0	14,112	14.61

R. H. Twedale in the *Engineering and Mining Journal*, Oct. 14, 21, and 28, 1899, published notes on the use of the products of crude petroleum, from which the following are condensed:

Crude petroleum is a hydrocarbon, often containing a small percentage of sulphur and oxygen as impurities. Its specific gravity may vary from 12 deg. to 70 deg. Baumé, but the greatest quantity produced ranges from 30 deg. to 45 deg. Baumé. The color of crude petroleum is usually a green brown, but it is found from a light-brown color, through the various shades of green to a jet black. It may be broken up by distillation into benzene, kerosene, and other distillates and residuums of various qualities, any one of which makes a very good fuel under certain conditions.

Gasoline, or petroleum distillate of more than 74 deg. Baumé, will never be used for fuel except to a very limited extent, since it and its closely associated distillates are always more valuable for other purposes, such as in internal combustion engines.

Benzene, or petroleum distillate from 55 deg. to 74 deg. Baumé, is the best of all liquid fuels, but the difficulty, danger and expense of transporting permit only its use in a few localities.

Kerosene or petroleum distillate of from 48 deg. to 35 deg. Baumé gravity is an excellent fuel. As a fuel for small boilers it is the best, because of its portability and the safety and facility with which it can be handled. The heavy distillates of petroleum known as neutral or solar oils have no particular advantage over kerosene as fuel save their high fire-test.

Crude petroleum may contain any portion of benzene and kerosene from nothing up to nearly 90 per cent, varying entirely

with the locality where it is produced. Of these two distillates, American crude petroleum contains roughly, from 50 to 75 per cent of kerosene and benzene; Russian from 15 to 50 per cent; Peruvian from 15 to 50 per cent.

After the benzenes and the kerosenes have been run off, there remains in the still an oil known by the various names of residuum, reduced oil, tar, fuel-oil, astatki, mazoot, petroleum refuse, etc. If this residuum is distilled still farther, neutral and lubricating oils distill over, or else, with certain forms of stills, decomposition sets in, and various products may be distilled over until nothing but a small amount of coke is left in the still.

The Russian crude oil contains a low percentage of kerosene and there is an enormous surplus of residuum, generally known as " astatki " or " mazoot," which cannot all be used for the manufacture of lubricating oils. This astatki is the fuel-oil par excellence for marine and locomotive work where a perfectly safe oil is required.

The petroleum fuel consumed in the United States is almost restricted to the use of crude oil, and this is not the fuel which will suit the general consumer. Crude oil is a most excellent and easily handled fuel, but it must be used with caution. It is absolutely unfit for use on a locomotive or steamer, since, in case of accident, it may catch fire and spread with startling rapidity. For such purposes no petroleum should be used that has a fire-test of less than 200 deg. to 250 deg. Fahr. A petroleum oil with a fire-test of 250 deg. Fahr. is a safer fuel than coal.

Residuum oil which has a fire-test of say 250 deg Fahr. to 300 deg. Fahr. is the most suitable for fuel on steamers. It is absolutely safe, as it cannot take fire and does not give off inflammable gases until heated to a temperature above that of boiling water. Such oil may be placed in a bucket and stirred with a red-hot poker without catching fire; shovelfuls of hot coals may be thrown into it, but they will be extinguished as if thrown in water.

It is probable that in the future petroleum fuel will be used more for marine purposes on account of economy in space and weight. California petroleum will probably be largely used for this purpose, as the production of crude petroleum there is being rapidly increased, and the oil is better suited by its quality for fuel than for refining purposes, owing to the small proportion of

volatile constituents and large proportion of heavy hydrocarbons. It is just the contrary with the petroleum found in the Eastern States, which is especially adapted to the manufacture of illuminating oils, owing to the large proportion of volatile hydrocarbons it contains.

The petroleum-fields of Peru somewhat resemble those of California. The crude oil is a good fuel for stationary boilers, and, if 40 per cent of benzene and kerosene are distilled off, the resulting residuum is an oil of about 22 deg. Baumé gravity and 260 deg. to 280 deg. fire-test, of moderate viscosity and containing no paraffin. It preserves its fluidity at low temperatures, and makes an excellent fuel for either locomotive or marine use.

Some of the advantages claimed for liquid fuel under boilers are:

1. Diminished loss of heat up the stack owing to the clean condition in which the tubes can be kept, and to the smaller amount of air which has to pass through the combustion-chamber for a given fuel consumption.

2. A more equal distribution of heat in the combustion-chamber, as the doors do not have to be opened, and consequently a higher efficiency is obtained.

3. With oil there is no chance of getting dirty fires on a hard run, as with coal.

4. A reduction in cost of handling fuel, since oil is handled mechanically or by gravitation, while with solid fuel manual labor is required.

5. No firing tools or grate bars are used, consequently the furnace lining and brickwork floors, etc., suffer less damage.

6. No dust nor ashes to cover or fill the tubes and diminish the heating surface, nor to be handled or carted away.

7. Petroleum does not suffer while being stored, while the deterioration of coal under atmospheric influence is well known.

8. Ease with which fire can be regulated, from a low to a most intense heat in a short time.

9. Absence of sulphur or other impurities and longer life of plates, etc.

10. Lessening of manual labor of fireman.

11. Great increase of steaming capacity.

For burning liquid fuel the best burner is that which atomizes

or sprays the fuel. By thus forming a fine mist an approximation to the theoretical fuel, gas, is obtained. Several methods are in use for this purpose. By some the oils are vaporized by heat; but this is applicable only to light oils, which are not much used. The favorite method is by having the burner so constructed that the oil is forced out in a spray and at the same time mixed with the air necessary for its combustion.

When using the fuel oil commonly used in the United States air sprayers are sufficient, as this oil is a distilled product and contains none of the very heavy solid portions of the crude oil. In Russia and in Canada, however, the case is different, as in these countries the fuel oil is the residuum from the distillation and contains all the heavy and none of the light oils. In this case steam is used as an atomizing agent, and it acts by virtue of its heat as well as its force.

To have the best results, the burner must be so regulated as to have a flame bordering on, but not quite, smoky. Thus sufficient and not too much air is obtained. The quantity of steam needed to atomize the oil at Moscow is 4 per cent of the water evaporated.

Besides use for heating boilers, liquid fuel has been used with good results in puddling-furnaces, glass-works, smelting-furnaces, brick-making, lime-burning, and in almost every place where coal would be used. In some cases where fine adjustment of temperatures has been needed it has been a strong competitor to gas itself.

Relative Calorific Values of Liquid Fuels. (From *Technical Paper* 37, *United States Bureau of Mines.*) A comparison of the heat of combustion of pure liquids was made by Irving C. Allen in the above-noted paper. Average values in calories per gram are given in the following table:

Substance.	Specific Gravity.	Average Calories per Gram.
Methyl alcohol CH_3OH	0.810	5,314
Ethyl alcohol C_2H_5OH	0.791	7,107
Hexane (paraffin) C_6H_{14}	0.677	11,603
Benzine C_6H_6	0.899	10,001
Commercial gasoline	0.710 –0.730	11,368
Commercial kerosene	0.790 –0.800	11,050
Crude California asphaltic petroleum (Average of 235 samples)	0.9462–0.9701	10,350

Properties of California Crude Oils. Crude oils of apparently the same gravity are often found to vary in calorific power. These variations are due to water in the oil. This water is often undetected and no correction is made for it due to use of the " so-called " gasoline test for water. This test is made by mixing equal parts of gasoline and oil and allowing the mixture to stand for twenty-four hours. The percentage of water can be read on a scale at the bottom of the test cylinder. F. S. Wade in *Power*, Nov. 14, 1911, states that this test rarely with any oil and almost never with the heavier oils reveals the full or correct amount of water present. In the same article, Mr. Wade presents a table showing the variation in the properties of California crude oils obtained from different districts. The maximum and minimum values given are as follows:

	Specific Gravity.	Degrees Baumé.	Pounds per Gallon.	Per Cent Sulphur.	B.T.U. per Pound.
Maximum	0.854	34.0	7.12	0.32	18,840
Minimum	0.988	11.7	8.24	4.43	19,400

The above figures are for oils entirely free from moisture. The B.T.U. per pint of the lightest oil was 17,270 and that of the heaviest oil was 19,030.

The accompanying table (from *Power*) gives what may be considered representative figures for the composition, weights and heat values of American oils:

PROPERTIES OF CRUDE OILS

Kind of Oil.	Composition by Weight.				Specific Gravity.	Lb. per Gallon.	B.T.U. per Pound.	
	Carbon.	Hydrogen.	Sulphur.	Oxygen.			By Test.	Computed.
Ohio	0.834	0.147	0.006	0.013	0.800	6.68	19,580	19,718
Pennsylvania, light	0.820	0.148	0.010	0.022	0.816	6.80	19,930	19,519
Pennsylvania, heavy	0.849	0.137	....	0.014	0.886	7.40	19,210	19,385
West Virginia, light	0.843	0.141	0.003	0.013	0.841	7.02	18,400	18,527
West Virginia, heavy	0.835	0.133	0.008	0.024	0.873	7.28	18,324	18,860
Texas	0.840	0.132	0.010	0.018	0.925	7.71	19,100	18,928
California	0.852	0.124	0.005	0.019	0.959	8.00	18,500	18,656
Average	0.839	0.139	0.007	0.018	0.871	7.27	19,006	19,086

The formula by which the computed results were obtained is not given.

The calorific value of California crude oils has a direct relation to the density, according to a table published in *Engineering News*, May 13, 1909, and reproduced below. The table shows that the thinner the oil the higher is its heating value per pound but the less per barrel.

RELATION OF DENSITY OF CALIFORNIA CRUDE OIL TO HEATING VALUE

Degree Baumé	Specific Gravity.	Weight per Barrel.	B.T.U. per Pound.	Thousands B.T.U. per Barrel.	Degree Baumé	Specific Gravity.	Weight per Barrel.	B.T.U. per Pound.	Thousands B.T.U. per Barrel.
10	1.000	350	18,380	6442	28	0.887	311	19,460	6051
11	0.993	348	18,440	6418	29	0.881	309	19,520	6030
12	0.986	346	18,500	6394	30	0.875	307	19,580	6008
13	0.979	343	18,560	6370	31	0.870	305	19,640	5990
14	0.972	341	18,620	6345	32	0.865	303	19,700	5973
15	0.966	339	18,680	6323	33	0.860	301	19,760	5954
16	0.959	336	18,740	6302	34	0.854	299	19,820	5935
17	0.953	334	18,800	6280	35	0.849	298	19,880	5917
18	0.947	332	18,860	6257	36	0.844	296	19,940	5901
19	0.940	330	18,920	6235	37	0.839	294	20,000	5885
20	0.934	327	18,980	6212	38	0.835	293	20,050	5865
21	0.928	325	19,040	6193	39	0.830	291	20,100	5846
22	0.922	323	19,100	6173	40	0.825	289	20,150	5827
23	0.916	321	19,160	6153	41	0.820	288	20,200	5808
24	0.910	319	19,220	6133	42	0.816	286	20,250	5789
25	0.905	317	19,280	6113	43	0.811	284	20,300	5770
26	0.899	315	19,340	6093	44	0.806	283	20,350	5751
27	0.893	313	19,400	6072	45	0.802	281	20,400	5732

The table on page 138 gives the calorific value of the oils from several of the oil fields of California. It is condensed from several extensive tables in Bulletin No. 19 of the U. S. Bureau of Mines (1911) and in Technical Paper No. 74 of the same bureau (1914). The calorific determinations were made in a Berthelot bomb of the Dinsmore-Atwater model.

Bakersfield oil is the oil most used on the Pacific Coast. Tests of this oil by Prof. Edmond O'Neill of the University of California, reported by C. R. Weymouth (*Transactions* Am. Soc. M.E., vol. xxx, p. 799) give an average ultimate analysis and heating value as follows: Carbon, 85 per cent; hydrogen, 12 per cent; sulphur, 0.8 per cent; nitrogen, 0.2 per cent; oxygen, 1 per cent; water, 1 per cent; B.T.U. per pound, 18,600.

CALORIFIC VALUE OF CALIFORNIA CRUDE OILS

(Condensed from Bulletin No. 19 (1911) and Technical Paper No. 74, U. S. Bureau of Mines)

Oil Field.	Number of Samples.	Average Specific Gravity at 15° C.	Average Degrees Baumé at 60° F.	Average Calorific Value.		
				Calories per Gram.	B.T.U. per Pound.	B.T.U. per Gallon.
Adams Canyon	3	0.9203	22.16	10,524	18,943	145,233
Arroyo Grande	2	.9745	13.66	10,208	18,374	149,185
Bardsdale	6	.9182	22.56	9,615	17,307	132,214
Brea Canyon	9	.9225	21.82	10,418	18,752	144,123
Coalinga	62	.9498	17.52	10,404	18,727	148,130
Coyote Hills	2	.9052	24.68	10,542	18,974	143,102
Fullerton	11	.9207	22.26	10,439	18,790	144,060
Kern River	40	.9645	15.16	10,307	18,553	148,980
La Brea	17	.9604	15.61	10,117	18,210	146,087
Lompoc	3	.9343	19.85	10,186	18,334	142,719
Los Angeles City	22	.9629	15.40	10,246	18,443	147,931
McKittrick	26	.9566	16.37	10,282	18,508	148,276
Midway	29	.9570	16.34	10,341	18,613	148,345
Newhall	9	.9245	21.93	10,469	18,845	145,019
Piru	13	.9143	23.29	10,336	18,604	141,642
Puente Hills	9	.8911	27.16	10,592	19,066	141,543
Santa Maria	40	.9053	24.68	10,400	18,720	141,187
Sespe	6	.8950	26.47	10,556	19,001	141,676
Summerland	6	.9652	15.06	10,302	18,544	149,106
Sunset	25	.9701	14.37	10,266	18,478	149,302
Wheeler Canyon	2	.8875	27.75	10,529	18,952	140,137
Whittier	18	.9386	19.20	10,449	18,808	147,062

Redondo, Cal., oil is also given by Mr. Weymouth (*Transactions* Am. Soc. M.E., vol. xxx, pp. 789 and 790) as having a range of moisture of 1.82 to 2.70; sulphur, 2.17 to 2.60 specific gravity; 14 to 18 deg. Baumé; B.T.U. per pound, 17,717 to 17,966.

Beaumont, Texas, oil analyzed as follows: (*Eng. News*, Jan. 30, 1902): Carbon, 84.60; hydrogen, 10.90; sulphur, 1.63; oxygen, 2.87. Sp. gr., 0.92; flash point, 142 deg. Fahr.; burning point, 181 deg. Fahr.; heating value per pound, calorimeter, 19,060 B.T.U.

Mexican Crude Oil (E. H. Peabody, Proc. Soc. Naval Architects and Marine Engineers, 1912). Mexican crude oil is very sticky and viscous at 80 deg. Fahr. On heating to 212 deg. Fahr. it turned to foam owing to the presence of water which failed to separate out. Sp. gr. at 60 deg. Fahr., 0.981, or 12.5 Baumé. Moisture and silt 3.5 per cent; flash point 310 deg. Fahr.; burning point 347 deg. Fahr.; B.T.U. per pound 17,551. It was successfully sprayed and burned under natural draft on being heated

to 270 deg. Fahr. at a pressure of 165 lb. The capacity fell off about 40 per cent from that obtained with the same apparatus with oil of 18 deg. Baumé.

Air Required for the Combustion of Oil (C. R. Weymouth, *Transactions*, Am. Soc. M.E., vol. xxx, p. 800). The table below shows the amount of air required for the combustion of oil of different grades. Text books give values ranging from 16 to 18 lb. of air or pound of oil, but 14 lb. would be a more nearly correct figure. The ordinary method of indicating and measuring the steam required to atomize the oil has been to express the quantity as a percentage of the actual amount of water evaporated in the boiler. This percentage ranges from about 2 to 5 and over, depending on the system of oil burning, type of burner, etc. While such a percentage of rating is convenient, it is inaccurate, in that the steam consumption of burners is proportional to the oil burned and not to the water evaporated. Various tests have shown that the steam consumption of oil burners ranges from 0.14 to over 0.5 lb. of steam per pound of oil. The average value of good performance is 0.3 lb. of steam per pound of oil. With good hand regulation on variable load this quantity should be somewhat increased, and is somewhat dependent on the gravity of the oil, temperature at the burners, etc. In stationary practice the use of air for atomizing has been practically abandoned.

WEIGHT OF AIR REQUIRED FOR THE COMBUSTION OF OIL OF DIFFERENT GRADES

Grade of Oil.	Light.	Medium.	Heavy.
Per cent of carbon	84.00	85.00	86.00
Per cent of hydrogen	13.00	12.00	11.00
Per cent of sulphur	0.80	0.80	0.80
Per cent of nitrogen	0.20	0.20	0.20
Per cent of oxygen	1.00	1.00	1.00
Per cent of water	1.00	1.00	1.00
Air chemically required per pound of oil, calculated, pound	14.25	14.02	13.79
Corresponding maximum CO_2 by volume in dry gases of combustion, per cent	15.16	15.52	15.89

The table below shows the actual and calculated weights of air supplied for the combustion of various grades of oil and various percentages of CO_2. Under present systems of firing the percentage of CO_2 in the flue gases is often as low as 4 per cent,

while with an ample supply of labor and the careful adjustment of dampers by hand it may be maintained as high as 13 per cent. With automatic control it has been found possible to maintain a percentage of CO_2 closely approaching the ideal.

ACTUAL AND CALCULATED WEIGHT OF AIR REQUIRED FOR COMBUSTION OF OIL

Per Cent CO_2, by Volume as Shown by Analysis of Dry Chimney Gases.	Light Oil. C, 84 per cent; H, 13; S, 0.8; N, 0.2; O, 1.00; H_2O, 1.00.		Medium Oil. C, 85 per cent; H, 12; S, 0.8; N, 0.2; O, 1.00; H_2O, 1.00.		Heavy Oil. C, 86 per cent; H, 11; S, 0.8; N, 0.2; O, 1.00; H_2O, 1.00.	
	Pounds of Air per Pound Oil.	Ratio Air Supply to Chemical Requirements.	Pounds of Air per Pound Oil.	Ratio Air Supply to Chemical Requirements.	Pounds of Air per Pound Oil.	Ratio Air Supply to Chemical Requirements.
4	51.40	3607	51.93	3704	52.45	3803
5	41.31	2899	41.71	2975	42.12	3054
6	34.58	2427	34.90	2490	35.23	2554
7	29.77	2089	30.04	2143	30.31	2198
8	26.17	1836	26.39	1883	26.62	1930
9	23.37	1640	23.56	1680	23.75	1722
10	21.12	1482	21.29	1518	21.45	1555
11	19.83	1391	19.43	1386	19.58	1419
12	17.76	1246	17.88	1276	18.01	1306
13	16.46	1159	16.57	1182	16.69	1210
14	15.36	1078	15.45	1102	15.55	1127
15	14.39	1010	14.48	1033	14.57	1056

Specifications for the Purchase of Fuel Oil. The U. S. Bureau of Mines has, in Technical Paper No. 3, 1911, the following specifications, which were drawn up for the government, covering (1) the number of heat-units obtained for a given price, (2) the physical character of the oil, (3) flash and burning points, and (4) amounts of extraneous matter.

Fuel oil should be either a natural homogeneous oil or a homogeneous residue from a natural oil; if the latter, all constituents having a low flash point should have been removed by distillation; it should not be composed of a light oil and a heavy residue mixed in such proportions as to give the density desired.

It should not have been distilled at a temperature high enough to burn it, nor at a temperature so high that flecks of carbonaceous matter began to separate.

It should not flash below 60 deg. Cent. (140 deg. Fahr.) in a closed Abel-Pensky or Pensky-Martens tester.

Its specific gravity should range from 0.85 to 0.96 at 15 deg. Cent. (59 deg. Fahr.); the oil should be rejected if its specific gravity is above 0.97 at that temperature.

It should be mobile, free from solid or semi-solid bodies, and should flow readily, at ordinary atmospheric temperatures and under a head of 1 ft. of oil, through a 4-in. pipe 10 ft. in length.

It should not congeal nor become too sluggish to flow at 0 deg. Cent. (32 deg. Fahr.).

It should have a calorific value of not less than 18,000 B.T.U. per pound; 18,450 B.T.U. per pound to be the standard. A bonus is to be paid or a penalty deducted according to the method stated under section 21, as the fuel oil delivered is above or below this standard.

It should be rejected if it contains more than 2 per cent water.

It should be rejected if it contains more than 1 per cent sulphur.

It should not contain more than a trace of sand, clay, or dirt.

MISCELLANEOUS LIQUID FUELS

Kerosene. Bulletin No. 43 of the U. S. Bureau of Mines (1912) gives a table of the heating value of kerosene, which is condensed below.

CALORIFIC VALUE OF KEROSENE

Sample.	Specific Gravity at 60 Deg. Fahr.	Degrees Baumé.	Flash-point.	H_2O.	H.	C.	O.	Heating Value by Calorimeter.			
								Calories.		B.T.U. per Pound.	
								High.	Low.	High.	Low
1	0.7912	46.9	113	0.57	14.33	85.16	0.51	11,068	10,376	19,922	18,676
2	0.7925	46.7	116	0.18	14.56	85.28	0.16	11,052	10,349	19,894	18,629
3	0.7930	46.5	118	0.26	14.37	85.40	0.23	11,045	10,351	19,881	18,632
4	0.7999	45.0	107	0.70	14.22	85.16	0.62	11,040	10,353	19,872	18,636

Samples 1, 2 and 3 were designated 150 deg. water white kerosene. Sample 4 designated as 120 deg. test " standard " kerosene purchased from Atlantic Refining Co., Pittsburgh.

From Bulletin 43, U. S. Bureau of Mines, 1912.

Gasoline. The table on page 142 is condensed from one given in Bulletin 43 of the United States Bureau of Mines.

ANALYSIS AND CALORIFIC VALUE OF GASOLINE

Specific Gravity at 60 deg. Fahr.	Degrees Baumé.	Per Cent by Weight of				Heating Value by Calorimeter.				Pound of Air per Pound of Fuel for Complete Combustion.
		Water.	Hydrogen.	Carbon.	Oxygen.	Calories.		B.T.U. per Pound.		
						High.	Low.	High.	Low.	
0.7122	66.6	2.09	14.83	83.31	1.86	11,434	10,718	20,581	19,292	14.74
0.7165	65.3	0.09	14.94	84.98	0.08	11,376	10,655	20,477	19,179	15.04
0.7168	65.2	0.10	14.88	85.03	0.09	11,404	10,686	20,527	19,235	15.04
0.7285	62.2	0.57	14.81	84.64	0.51	11,337	10,625	20,407	19,125	14.96
0.7289	62.1	....	.....	.....	....	11,323	10,611	20,381	19,100	.....
0.7292	62.0	0.46	14.75	84.84	0.41	11,328	10,616	20,390	19,109	14.96
0.7294	62.0	0.84	14.80	84.46	0.75	11,327	10,613	20,389	19,103	14.91
0.7301	61.8	....	.....	.....	....	11,337	10,625	20,407	19,125	.....

Denatured Alcohol. Bulletin No. 43, U. S. Bureau of Mines gives the following calorific values of denatured alcohol.

CALORIFIC VALUE OF DENATURED ALCOHOL

Specific Gravity at 60° Fahr.	Per Cent by Weight.				Heating Value.			
	Water.	Hydrogen.	Carbon.	Oxygen.	Calorimeter.			
					Calories.		B.T.U. per Lb.	
	From Specific Gravity.	From Analysis.	From Analysis.	From Analysis.	High.	Low.	High.	Low.
0.8181	8.3	12.64	47.17	40.19	6460	5850	11,628	10,530
0.8188	8.5	12.74	47.47	39.79	6528	5913	11,750	10,643
0.8191	8.7	12.73	47.28	39.99	6451	5838	11,612	10,508
0.8192	8.7	12.75	47.30	39.95	6440	5825	11,592	10,485
0.8196	8.9	12.75	47.02	40.23	6447	5832	11,605	10,498
0.8198	8.9	12.73	46.92	40.35	6415	5800	11,547	10,440
0.8206	9.2	12.71	47.72	39.57	6423	5804	11,561	10,447
0.8225	9.9	12.60	45.97	41.43	6374	5766	11,473	10,379
0.8241	10.5	12.47	46.87	40.66	6377	5775	11,479	10,395

Tar (C. F. Pritchard, in *The Engineer* (Chicago), April 1, 1903). Under normal conditions coal tar has a value for other purposes exceeding its fuel value considerably; but this is not always true, and it is seldom that what is ordinarily called water-gas tar can be disposed of at a price near its fuel value.

The yield of coal tar produced by the distillation of coal varies according to the coal and the method employed, from 4.5 to 6.5

per cent of the weight of coal. Its specific gravity is about 1.25, a gallon weighing 10.3 lb. The ultimate analysis of a tar made from a standard gas coal, in a medium-sized gas works, is as follows:

Carbon, 89.21; hydrogen, 4.95; nitrogen, 1.05; oxygen, 4.23; ash, trace; volatile sulphur, 0.56. Heating value by Dulong's formula, 15,781 B.T.U. per pound. A series of tests in a bomb calorimeter gave 15,708 British thermal units, the tar being practically freed from water.

CALORIFIC VALUE OF AMERICAN OILS

Name or Location.	Sp.Gr.	Carbon.	Hydrogen.	O + N	Oxygen.	Nitrogen.	Calories.	B.T.U.	Authority.
Heavy petroleum, W. Virginia	0.873	83.5	13.3	3.2	.....	.....	10,180	18,324	St.-Claire Deville
Light petroleum, W. Virginia	0.841	84.3	14.1	1.6	.....	.....	10,223	18,400	"
" " Pennsylvania	0.826	82.0	14.8	3.2	.....	.....	9,963	17,930	"
Heavy petroleum, Pennsylvania	0.886	84.9	13.7	1.4	.....	.....	10,672	19,210	"
" " Ohio	0.887	84.2	13.1	2.7	.....	.....	10,399	18,718	"
American oil sold in Paris	.....	83.4	14.7	1.9	.....	.....	9,771	17,590	"
" " heavy, sold in Paris	.....	86.9	13.1	...	.....	.....	10,913	19,643	Mahler
" " refined, sold in Paris	.....	85.5	14.2	0.3	.....	.....	11,045	19,881	"
" naphtha, sold in Paris	.....	80.6	15.1	4.3	.....	.....	11,086	19,955	"
" crude, sold in Paris	.....	83.0	13.9	3.1	.....	.....	11,094	19,970	"
Heavy Pennsylvania oil	0.886	84.9	13.7	...	1.4	.....	10,680	19,224	Robinson
" W. Virginia oil	0.928	88.3	13.9	...	0.8	.....	10,102	18,184	"
No Wood, Wyoming	0.996	.....	.....	...	.....	.....	10,927	19,668	E. E. Slosson and
Shoshone Reservation, Wyoming	.....	.....	.....	...	.....	.....	10,883	19,590	L. C. Colburn
Salt Creek, Natrona Co., "	.....	.....	.....	...	.....	.....	10,813	19,463	"
Oil Mt., Natrona Co., "	.....	.....	.....	...	.....	.....	10,743	19,337	"
Newcastle, Weston Co., "	.....	.....	.....	...	.....	.....	10,447	18,805	"
Little Popo, Agie, "	0.900—0.921	.....	.....	...	.....	.....	10,430	18,774	"
Lander	0.8565—0.8635	.....	.....	...	.....	.....	10,883	19,590	"
Oil Creek, Pa	0.730	82.0	14.8	...	3.2	.....	11,606	20,890	Anonymous
Scotia well, W. Va	.....	86.6	12.9	...	.....	0.54	11,801	21,240	"
Cumberland, W. Va	.....	85.2	13.4	...	.....	.....	11,483	20,670	"
Bothwell, Canada	0.857	84.3	13.4	...	2.3	.....	11,339	20,410	"
Petrolea, Canada	0.870	84.5	13.5	...	2.0	.....	11,406	20,530	"
Residuum, Virginia oil	0.860	87.1	11.7	...	1.2	.....	10,667	19,200	"
Pennsylvania crude	0.938	84.9	13.7	...	1.4	.....	11,520	20,736	"
California, Hayward Company	.....	86.9	11.8	...	.....	1.1	11,728	21,110	"
Lima, Ohio	.....	80.2	17.1	2.7	.....	.....	12,000	21,600	Mayer
Mineral seal	0.83	83.3	13.2	...	.....	.....	11,147	20,065	Stillman & Jacobus

CALORIFIC VALUE OF FOREIGN OILS

Name or Location.	Sp. Gr.	Carbon.	Hydrogen.	O +N	Oxygen.	Nitrogen.	Sulphur.	Calories.	B.T.U.	Authority.
Petroleum										
Salo, Parma	0.786	84.0	13.4	1.8	.....	.....	.....	10,120	18,216	St.-Claire Deville
Pechelbronn (distilled)	0.912	86.9	11.8	...	1.3	.....	.....	9,708	17,475	"
Crude, Pechelbronn	0.892	85.6	9.6	...	4.5	0.25	.....	10,020	18,036	"
Schwabwiller, Lower Rhine	0.861	86.2	13.3	0.5	.....	.....	.....	10,458	18,781	"
Galicia, East	0.872	82.2	12.1	5.7	.....	.....	.....	10,005	18,010	"
" West	0.885	85.3	12.6	2.1	.....	.....	.....	10,231	18,416	Mahler
Baku (heavy)	....	87.0	12.9	...	.....	.....	.....	10,843	19,517	"
Novorossik	....	84.9	11.6	9.5	.....	.....	.....	10,328	18,590	"
Crude Naphtha, Balchany	0.884	87.4	12.5	0.1	.....	.....	.....	?11,070	19,926	"
Residuum, Balchany	0.928	87.1	11.7	1.2	.....	.....	.....	?11,700	21,060	"
Black oil, Weyser works	....	86.5	12.0	1.5	.....	.....	.....	?10,760	19,368	"
Light oil, Baku	0.884	86.3	13.6	0.1	.....	.....	.....	11,460	19,700	"
Heavy oil, Baku	0.956	86.6	12.3	1.1	.....	.....	.....	10,800	19,440	"
Timaacon, Java	0.923	87.1	12.0	0.9	0.9	.....	.....	10,831	19,496	"
Madja, Java	....	83.6	14.0	2.4	.....	.....	.....	9,593	17,267	"
Kendong, Java	....	85.0	11.2	2.8	.....	.....	.....	10,183	18,330	"
Ogaio	0.985	87.1	10.4	...	2.5	.....	.....	.....	18,145	Anonymous
Paraffin oil (pressed)	....	.....	.....	...	.....	.....	.....	10,172	18,310	"
Russia, crude	0.884	86.3	13.6	...	0.1	.....	.....	12,650	22,628	Goulishambaroff
" "	0.938	86.6	12.3	...	1.1	.....	.....	10,800	19,440	"
Baku, Russia, crude	0.938	.....	.....	...	.....	.....	.....	11,200	20,160	"
" " refuse	0.928	87.1	11.7	...	1.2	.....	.....	10,700	19,200	"
" " crude	0.928	.....	.....	...	.....	.....	.....	11,760	21,168	"
" " astatki	....	84.49	13.96	...	1.25	.....	.....	10,340	18,611	W. Thompson
Schist Oil										
Crude from Vaquas, Ardèche	0.911	80.3	11.5	8.2	.....	.....	.....	9,046	16,282	St.-Claire Deville
Autun	....	79.7	11.8	8.6	.....	.....	.....	9,950	17,910	"
Nouvelle Galles	....	83.7	11.8	4.4	.....	.....	.....	10,381	18,686	Mahler
Heavy	....	.....	.....	...	.....	.....	.....	9,654	17,377	St.-Claire Deville
Crude	....	.....	.....	...	.....	.....	.....	8,623	15,520	"
Acid residuum	....	.....	.....	...	.....	.....	.....	9,836	17,705	"
From la Condamine	....	.....	.....	...	.....	.....	.....	9,612	17,300	"

CALORIFIC VALUE OF FOREIGN OILS—*Continued*

Name or Location.	Sp.Gr.	Carbon.	Hydrogen.	O+N	Oxygen.	Nitrogen.	Sulphur.	Calories.	B.T.U.	Authority.
Schist Oil—Continued.										
Gas oil from Paris Works	1.044	82.0	7.6	10.4	.....	.....	.....	8,916	16,050	St.-Claire Deville
Ozokerite, Boryslaw	....	85.2	14.7	0.11	.....	.....	.....	11,163	20,093	Mahler
Ozokerite oil	....	.....	.....	...	.....	.....	.....	10,648	19,122	St.-Claire Deville
Heavy pine oil (blue, fluorescent)	....	84.8	10.5	4.7	.....	.....	.....	10,081	18,146	"
Blast furnace oil, Coatbridge, Eng	....	83.64	10.59	...	5.94	.....	0.087	8,933	16,080	W. Thompson
Olive oil (pressed)	....	.....	.....	...	.....	.....	.....	9,328	16,790	Stohmann
" " "	....	.....	.....	...	.....	.....	.....	9,473	17,050	"
Poppy seed oil (pressed)	....	.....	.....	...	.....	.....	.....	9,442	16,996	"
Rape seed oil (pressed)	....	.....	.....	...	.....	.....	.....	9,489	17,080	"
" " " "	....	.....	.....	...	.....	.....	.....	9,619	17,314	"
Sperm oil	....	.....	.....	...	.....	.....	.....	10,000	18,000	Gibson

CALORIFIC VALUE OF ASPHALT AND BITUMEN

Name or Location.	Fixed.	Volatile.	Total Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Calories.	B.T.U.	Authority.
Bitumen, pure	24.80	72.44	77.68	8.02	14.30	.....	.....	2.76	8408	15,134	Johnson
Boghead shale, Australia	....	.....	83.17	10.04	6.15	0.46	.....	...	9134	16,431	Bunte
Asphalt, Dead Sea	....	.....	76.36	9.16	11.53		3.00	3.62	8900	16,020	Mahler
" Big Horn, Wyoming	....	.....	....	.....	.....	.....	.....	...	9532	17,159	Slosson
" Wallace Creek, "	....	.....	....	.....	.....	.....	.....	...	6307	11,953	"

CHAPTER VIII

GASEOUS FUELS

THE heat of combustion of gaseous combustibles has been determined for a great many compounds, definite and pure. That of the industrial gases has been determined by different operators and in different ways, with more or less happy results. Its determination is often one of the greatest commercial interest, since it is used in domestic heating as well as in industrial appliances, where it is necessary to obtain definite, regular working. It serves also to furnish motive power to gas-engines, in which the heat of combustion is not without importance. Finally, it is well to know the heat produced in air or water-gas apparatus, if we wish to reach the best condition for their production and use.

For heating steam-boilers gas has given good results and a very high evaporative effect. It is easily regulated, and thus any required heat can be produced by simply turning a valve. No smoke is generated, no soot or deposit of any kind produced in the flues, and there are no ashes to take out of the ash-pit. The fireplace seldom needs repairing, and the boiler is heated evenly and regularly, there being no danger of burning out in strongly heated spots, as no such spots exist.

In metallurgical furnaces, gas possesses a decided advantage in its long, clean, easily managed, intense flame, and this advantage has been long recognized. A flame of 25 ft. or more in length is easily produced, and it is practically uniform for its whole extent. Part of the heat usually lost up the chimney can be utilized to heat the air-supply, and no more is supplied than just enough for perfect combustion.

Using gas as fuel enables the metallurgist to use poor grades of coal, and all variations in quality may be eliminated, a uniform product being had by storing the gas in a holder, or by making proper arrangement of different generators so that an average will be obtained. In several cases where hand-fed coal fires have been tried against fires burning gas from the same coal, better

results have been obtained, due to the possibility of more closely adjusted regulation. The tests made at Brieg may be cited. Here each boiler had 141.25 sq.ft. of heating-surface and steam-pressure 90 to 100 lb. per sq.in.

No. 1 boiler was hand-fired; No. 2 was gas-fired. The evaporation in pounds per pound of fuel was:

No. 1.....	8.34	8.74	8.28	4.02	2.569	2.764
No. 2.....	9.86	9.73	10.07	5.44	3.251	3.158
Increase.....	18%	12%	20%	35%	25%	14%

HEAT OF COMBUSTION OF GASES FROM ANALYSIS

When the chemical composition of a gas is known exactly, its heat of combustion can be correctly calculated; but in absence of a correct analysis, the calorimeter must be used.

Knowing the proximate composition of a combustible gas, that is, the proportion of chemically defined components as well as their heats of combustion, it is sufficient to add the numbers obtained for each constituent gas. Take, for example, the analysis of illuminating gas of Manchester as given by Bunsen:

Hydrogen	45.58
Marsh gas (CH_4)	34.90
Carbon monoxide	6.64
Ethylene (C_2H_4)	4.08
Butylene (C_4H_8)	2.38
Sulphurous acid H_2S	0.29
Nitrogen	2.46
Carbon dioxide	3.67
	100.00

The calculation is as follows:

Components.	Number of Liters per Cubic Meter.	Weight per Cubic Meter at 0° C. and 70 mm., Grams.	Heat of Combustion per Cubic Meter, Calories.	Calculated Calories, in Gas.
Hydrogen.....	455.8	89.61	3,066	1395
Marsh gas, CH_4.....	369.0	715.58	9,340	3169
Olefiant gas, C_2H_4....	40.8	1251.94	14,980	611
Butylene, C_4H_8.....	23.8	2503.88	29,042	690
Carbon monoxide....	66.4	1251.50	3,057	201
Sulphurous acid, H_2S..	2.9	2551.99	11,400	33
Total calories per cubic meter.....				6099

City of Manchester gas, as analyzed by Bunsen, gives, then, with complete combustion, 6099 calories per cubic meter (685 B.T.U. per cubic foot).

If, however, only the actual ultimate composition of the gas is known or the total percentage of carbon, hydrogen, oxygen and nitrogen, then the calculated result will differ from the experimental one. This is because the heat units of the elements added together do not make those of the compound, as the heat of combination of the different constituent gases is not allowed for. If this factor is known, then it can be used as a correction and the correct heat determined.

This heat of combination of the elements to form the component gases will be seen in comparing the calculated and the actual heat of combustion of the following gases:

Gases.	Formula.	Carbon.	Hydrogen.	Calculated Heat, Calories.	Actual Heat, Calories.	Difference.
Marsh gas.....	CH_4	75.	25.	14,685	13,343	+1342
Olefiant gas.....	C_2H_4	85.7	14.3	11,859	12,182	− 323
Acetylene.....	C_2H_2	92.3	7.7	10,114	12,142	−2028
Benzene.....	C_6H_6	92.3	7.7	10,114	12,410	−2296

It will also be seen, that although two gases may have the same percentage composition of the elements, yet the heat of combustion may be different owing to the action of the various physical forces at work in molecular condensation, etc.

COAL GAS

Coal gas is obtained by the destructive distillation of bituminous or semi-bituminous coal in closed retorts. The gas is washed and purified to remove the ammonia, tar and other impurities. The residue remaining in the retort is coke.

The heat of combustion of illuminating gas obtained from the distillation of coal in closed retorts is very variable. It depends not only on the nature of the fuel, but also on the rapidity of the distillation and the heat by which it is accomplished. The heat of combustion varies from 570 to 605 B.T.U. per cubic foot. It cannot be represented by any average number.

According to Bueb-Dessau, the illuminating gas of the same city during the same day will sometimes vary 20 per cent. Dr.

Birchmore reports the same result from his examinations of the gas of Brooklyn, N. Y.

From several experiments which he made, Bueb-Dessau* thought that the heat of combustion of illuminating gas was directly proportional to the candle power. The experiments of Aguitton show the contrary. He concluded from his determinations that each illuminating gas of different candle-power has a definite heat of combustion which corresponds to the intensity of the light. Aguitton's experiments were carried on with more than a hundred samples, rich and poor, the former kind from cannel coal, the latter from the end of the run carried to an extreme. He represented by the following formula the relation between candle-power and heat of combustion of a gas:

$$c = i \times 352.6 + 2280,$$

in which c represents the heat of combustion and i the candle-power. The formula seems to be applicable only between the limits at which it has been verified—from 5 to 15 candles. Aguitton's determinations were made with the calorimetric bomb.

The following table gives a résumé of his observations:

Candle-power.	Heat of Combustion Calories per Cubic Meter.
5	4043
6	4395
7	4748
8	5101
9	5453
10	5806
11	6158
12	6511
13	6864
14	7216
15	7569

$$\frac{7569-4043}{10} = 352.6, \text{ coefficient adopted.}$$

* Bueb-Dessau cites the following among others:

	Candle-power.	Heat-value.
Gas of Dessau	14.	4400 calories
Gas of Bremen	21.9	5977 "
Gas from cannel coal	26.0	6559 "

The three samples of illuminating gas, analyzed and burned in the bomb by Mahler and given in the table on page 152, call for the following observations: Gas from Niddrie cannel coal, having the greatest calorific power per cubic meter has the least calorific power per kilogram, because its density is greater than that of the other two. The richest in hydrogen by volume (Lavillette) is the lowest in calorific power per cubic meter, while the poorest in hydrogen by weight is the richest in calories per cubic meter. These are due to the low density of hydrogen, which has a lower calorific value by volume than the other hydrocarbons present in illuminating gas.

A cubic meter of hydrogen develops 3091 calories in burning; a cubic meter of marsh gas develops 10,038 calories; a cubic meter of olefiant gas, 15,250 calories.

The table herewith gives the calorific value of illuminating gas made from different kinds of coal, in closed retorts. The tests were made at Ann Arbor, Mich., in 1909 by A. H. White and Perry Baker, and are reported in Bulletin No. 6 of the U. S. Bureau of Mines.

CALORIFIC VALUE OF ILLUMINATING GAS FROM VARIOUS KINDS OF COAL

(Bulletin No. 6, U. S. Bureau of Mines, 1911)

Kind of Coal.	Analysis of Coal.					Calorific Value of Coal, B.T.U.	Gas per Pound of Dry Coal, Cu.ft.	Calorific Value of Gas per Cu.ft., B.T.U.
	Moisture.	Ash.	Volatile Matter.	Fixed Carbon.	Sulphur.			
Pittsburgh....	1.92	6.41	32.82	58.85	1.12	14,026	4.9	...
Pittsburgh....	2.18	7.53	32.96	57.33	1.43	13,815	5.0	593
Pittsburgh....	2.05	6.68	33.25	58.02	1.49	13,955	5.4	550
Kentucky....	2.46	6.25	31.18	60.11	0.43	13,885	4.9	578
New Mexico..	2.23	15.10	31.42	51.25	0.67	12,438	4.7	606
Colorado.....	7.17	14.55	32.36	45.92	1.00	10,953	5.2	566
West Virginia.	1.28	5.57	30.65	62.50	1.53	14,531	5.3	555
New Mexico..	2.32	8.94	32.18	56.56	0.70	13,385	5.0	618
Wyoming.....	22.56	5.81	32.26	39.37	0.36	9,592	7.0	502
Colorado.....	0.71	18.32	24.14	56.83	0.57	12,436	5.0	550
Tennessee....	3.13	2.15	34.09	59.73	0.72	14,245	5.7	575
Alabama.....	2.71	4.29	29.13	63.87	0.50	13,990	5.3	538
Illinois.....	4.66	7.19	34.44	53.71	1.96	12,919	4.3	568
Kentucky....	3.17	3.76	32.40	60.67	0.45	14,200	5.0	561
Michigan.....	9.28	5.35	31.67	53.70	0.98	12,456	4.7	526
Pittsburgh....	2.43	4.88	32.70	59.99	0.85	14,036	5.3	664
West Virginia.	1.27	6.83	29.02	62.88	1.18	14,344	5.1	557

HEATING VALUE OF ILLUMINATING GAS (MAHLER)

Name.	Density.	Analysis by Weight.					Heat of Combustion, Calories.	
		Carbon in Hydrocarbons.	Hydrogen.	Carbon Monoxide.	Carbon Dioxide.	Oxygen, Nitrogen and Sulphur.	Per Cubic Meter at 0° C. and 760 mm.	Per Kilogram.
Niddrie cannel..	0.6367	43.33	13.50	16.84	9.26	14.96	6365	7,735
Commentry coal.	0.4046	43.74	21.46	24.96	7.08	5.75	5804	11,100
Lavillette gas...	0.4033	42.25	21.34	21.23	6.83	8.33	5602	10,764

GAS FROM GAS GENERATORS

Gas generators, instead of transforming the fuel into carbon dioxide and water in a single combustion, produce this change in two distinct burnings, making a combustible gas which is afterwards burned with air.

Coal, for example, is burned in such a manner by feeding with an insufficient supply of air that a gaseous mixture is produced, containing principally carbon monoxide and nitrogen from the air. As the combustion has been well or poorly managed, it contains a less or greater quantity of carbon dioxide, the production of which is avoided as much as possible. This is done by giving to the fuel only just enough air to form carbon monoxide, and not enough to form carbon dioxide, even partially, and by making the bed of fuel quite deep. Carbon dioxide formed in the lower portion of the fuel bed, takes up another atom of carbon in passing through the upper part of the fire, and is thus converted to carbon monoxide. If the fuel bed is too shallow, this conversion will not take place.

The heat produced by the partial combustion to carbon monoxide cannot be utilized, and consequently an important portion of the calorific power of the coal is lost. Generator gas is then lower in calories, and inferior to coal gas, as commonly made by distillation.

One pound of carbon burned to carbon monoxide produces 4450 B.T.U., while if burned to carbon dioxide it generates 14,000 B.T.U. There is lost, then, in burning carbon to carbon

CALORIFIC VALUE OF EUROPEAN COAL GAS

Name or Location.	Hydrogen.	Methane, CH_4.	Acetylene, C_2H_2.	Illuminants.	Carbon Dioxide.	Carbon Monoxide.	Oxygen.	Nitrogen.	Water.	Calories, per Cu. Meter.	B.T.U. per Cu. Foot.	Authority.
Birmingham, Eng.	40.23	39.00	....	4.76	1.50	4.05	0.36	10.10	..	6,283	671	Thwaite
Coke ovens, Brymbo	45.9	22.9	....	3.7	3.3	9.9	....	13.5	0.8	5,234	559	Chas. Hunt
Bonn, Germany	39.80	43.12	....	4.75	3.02	4.66	....	4.65	...	6,666	712	Thwaite
Brighton, Eng	51.62	38.15	....	3.76	0.03	4.14	0.23	2.07	...	6,320	675	"
Bristol, Eng	44.57	40.70	....	4.58	....	4.77	0.27	5.11	...	6,563	701	"
Chemnitz, Germany	51.29	36.45	....	4.91	1.08	4.45	....	1.41	...	6,395	683	"
Cologne, Germany	56.90	34.40	....	3.50	....	5.20	....	....	...	6,095	651	"
Dresden, Germany	48.70	33.40	....	3.00	1.50	8.00	1.40	4.00	...	5,711	610	"
Edinburgh, Scotland	33.24	42.93	....	12.23	0.35	6.61	1.00	3.64	...	8,370	894	"
Glasgow, Scotland	39.18	40.26	....	10.00	0.29	7.14	0.06	3.07	...	7,774	830	"
Gloucester, England	48.89	38.25	....	4.95	0.03	4.64	9.51	2.73	...	6,563	701	"
Hanover, Germany	46.27	37.55	....	3.17	0.81	11.19	....	1.01	...	6,188	661	"
Heidelberg, Germany	44.00	38.40	....	7.27	0.37	5.75	....	4.23	...	6,797	726	"
Ipswich, England	43.23	38.73	....	4.53	0.06	2.46	0.12	10.84	...	6,272	670	"
Leeds, England	40.26	42.74	....	7.28	0.34	5.02	0.07	4.32	...	7,247	774	"
Liverpool, England	36.44	44.28	....	7.90	1.70	3.39	0.19	6.10	...	7,415	792	"
London G. L. & Co. Co., Eng.	47.99	37.64	....	4.41	....	3.75	0.26	5.95	...	6,320	675	"
" " " " "	49.2	34.2	....	4.7	....	7.5	0.1	4.3	...	6,114	653	Chas. Hunt
" So. Metropolitan, Eng.	53.14	36.55	....	2.92	0.09	4.11	....	3.19	...	6,030	644	Thwaite
Manchester, England	45.58	34.90	....	6.46	3.67	6.64	....	2.46	...	6,535	698	"
Newcastle-under-Lyme, Eng.	46.31	39.01	....	4.53	0.08	3.74	0.11	6.22	...	6,395	683	"
Newcastle-on-Tyne, Eng	50.50	36.71	....	3.62	0.28	3.37	0.23	5.29	...	6,095	651	"
Norwich, Eng	53.79	36.11	....	3.26	0.27	3.40	0.14	3.03	...	6,049	646	"
Nottingham, Eng	45.52	39.66	....	5.63	0.81	5.63	0.24	2.51	...	6,797	726	"
Paris, France	50.10	33.10	....	5.80	1.50	6.30	0.50	2.70	...	6,244	667	"
Preston, England	43.95	39.33	....	6.22	0.84	4.62	0.25	4.79	...	6,825	729	"
Redhill, England	48.18	39.41	....	4.40	0.74	3.41	0.49	3.37	...	6,498	694	"
St. Andrews, Scotland	36.63	42.13	....	10.04	2.73	5.16	0.48	2.83	...	7,827	836	"
Sheffield, England	43.05	43.05	....	6.28	0.24	4.72	0.10	2.56	...	7,163	765	"
Southampton, England	53.59	38.15	....	3.76	0.03	4.14	0.23	2.07	...	6,413	685	"
" "	46.2	37.5	....	4.9	....	6.8	....	4.6	...	5,768	616	Chas. Hunt
Oil Gas	31.61	46.17	....	16.29	....	0.14	0.73	5.06	...	8,124	869	Rogers
" Pintsch	18.4	42.9	11.3	15.5	....	.....	....	11.8	...	12,660	1320	Worstall and Burwell

monoxide in a gas generator about 30 per cent of the available heat units.

At first sight this method of working seems irrational, but for obtaining high temperatures there are practical advantages, whose importance far exceeds the loss of heat in the gas generator. It permits much more elevated temperatures, and the recovery of a large portion of the heat, which in direct systems of heating in high temperature furnaces passes to the chimney as a complete loss. There is actually an economy in the ordinary metallurgical methods even with this loss.

By means of gas generators there are produced three kinds of gaseous fuel: *producer gas*, formed by the incomplete combustion of the fuel, with the production of a mixed gas containing carbon monoxide and hydrogen compounds; *water gas*, formed by the decomposition of water by carbon at a high temperature, with production of carbon monoxide, hydrogen, and hydrogen compounds; and *mixed gas*, formed by the mixture of the two preceding gases by a process which combines the production of the two gases in the same furnace.

PRODUCER GAS

Producer gas results from incomplete combustion, and its formation causes a loss of one-third of the heat units that would result from the complete combustion of the fuel. The gas contains, naturally, the nitrogen of the air used, to which must be added that of the air necessary to change the carbon monoxide and the hydrogen to carbon dioxide and water. The heat of combustion and the composition varies considerably, due to variation in the composition and calorific value of the coal used in the producer.

The proportion of nitrogen in producer gas reaches 56 to 60 per cent; that of carbon monoxide, 21 to 32 per cent; that of hydrogen, from traces to 17 per cent. The theoretical calculation for the combustion of carbon in air to a gas containing only carbon monoxide and nitrogen gives respectively 34.7 and 65.3 per cent.

The composition of air is, in round numbers, 79 parts of nitrogen and 21 parts of oxygen. Oxygen weighs 1.430 grams per liter. The atomic weight of carbon is 12, and of oxygen 16.

$$12 : 16 = 1000 \text{ grams} : 1333 \text{ grams}.$$

A kilogram of carbon needs, then, for combustion to carbon monoxide $1\frac{1}{3}$ kilograms of oxygen. Since a liter of oxygen weighs 1.430 grams, 1333 grams would occupy 932 liters. These 932 liters combined with carbon to form carbon monoxide will have a volume of 1864 liters. Multiplying 932 liters by the coefficient 4.77 (see Table 17), we obtain the corresponding volume of the air or 4445 liters. The gases of combustion will be composed then of these 4445 liters of air and the 932 liters of increase in volume, or 5377 liters of gas for 1 kilogram of carbon. The 4445 liters of air will contain (at 79 per cent) 3513 liters of nitrogen, or 65.3 per cent.*

The calculation is more complicated when we have fuel containing hydrogen, as one portion of the oxygen disappears by its combination with the hydrogen to form water. Take for example, a coal containing 90 per cent of carbon, 5 per cent of hydrogen, and 5 per cent of oxygen. Suppose 1 kilogram of this coal, under theoretical conditions, burned in a producer, i.e., with perfect transformation of the carbon into carbon monoxide and no residues. This coal contains 900 grams of carbon, 50 grams of hydrogen, 50 grams of oxygen. Nine hundred grams carbon produce 2100 grams carbon monoxide, requiring 1200 grams of oxygen. Twelve hundred grams of oxygen occupy 839 liters. Fifty grams of hydrogen produce 450 grams of water, and require 400 grams of oxygen. These 400 grams of oxygen occupy 279 liters. But the coal itself contains 50 grams of oxygen, occupying 35 liters.

We have, then, $839+279-35=1083$ liters of oxygen required. The air needed is $1083\times4.77=5166$ for the incomplete combustion of 1 kilogram of carbon. These 5166 liters contain 4080 liters of nitrogen.

To obtain the total volume of gases produced by the incomplete combustion, we should add to the volume of the air introduced the volume due to the formation of carbon monoxide. This is equal to the volume of the oxygen used, or 839 liters. We have, then, $5166 + 839 = 6005$ liters. But a quantity of oxygen has disappeared corresponding to the formation of the water, or

* One pound of carbon requires 1.333 lb. of oxygen; 1 cu.ft. of oxygen weighs 0.08926 lb.; 1.333 lb. measures 14.93 cu.ft. These would give 29.86 of CO. $14.93\times4.77=71.216$, and $71.216+14.93=86.146$, volume of gases of combustion. These contain 56.26 cu.ft. of nitrogen.

279−35=244 liters (35 liters exists in the coal as above), and 6005−244=5761 liters of gas produced by the incomplete combustion of 1 kilogram of coal.

Now, 5166 liters of air contain 4079 liters of nitrogen, which would form $\frac{4079}{5761}$, or 70.8 per cent of the total gas. All these are based on a temperature of 0 deg. Cent. and a pressure of 760 mm.*

Mahler determined the heat of combustion of a sample of gas from the Follembray glass-house, and found its composition by volume, using coal from Béthune, to be:

Marsh gas	2
Hydrogen	12
Carbon monoxide	21
Carbon dioxide	5
Nitrogen	60
	100

The heat of combustion calculated from its composition is:

Marsh gas	0.02 × 10038 =	200.8
Hydrogen	0.12 × 3091 =	370.9
Carbon monoxide	0.21 × 3043 =	639.0
		1210.7

With the bomb he found 1212 calories.

WATER GAS AND MIXED GAS

Water gas is produced by the decomposition of water at high temperatures by fuels containing but little hydrogen, such as

* One pound of coal would contain 6300 grains of carbon, 350 grains of oxygen, and 350 grains of hydrogen; 0.90 lb. of carbon produces 2.1 lb. of carbon dioxide, and requires 1.2 lb. oxygen; 1.2 lb. oxygen occupies 13.44 cu.ft.; 0.050 lb. of hydrogen produces 0.450 lb. of water, and requires 0.400 lb. of oxygen, or 4.48 cu.ft. The 0.05 lb. of oxygen in the coal occupies 0.56 cu ft. Then 13.44+4.48−0.56=17.36 of oxygen required; 17.36×4.77=82.81 cu.ft. of air, containing 65.41 cu.ft. of nitrogen. Total gases, 82.81+13.44 −3.92=92.33 total volume of gas, and

$$\frac{65.41}{92.33}=70.8 \text{ per cent.}$$

CALORIFIC VALUE OF PRODUCER GAS MADE FROM DIFFERENT VARIETIES OF AMERICAN COAL

(Condensed from Bulletin No. 13, U. S. Bureau of Mines, 1911)

Kind of Coal.	Coal.						Gas.	
	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	B.T.U. per Pound as Fired.	Gas Made per Pound of Coal as Fired, Cu.ft.	B.T.U. per Cubic Foot.
Alabama	3.05	29.53	54.78	12.64	1.15	12,953	75.4	152.0
"	3.76	33.45	53.29	9.50	0.86	12,865	58.1	143.5
Arkansas	2.74	9.70	71.95	15.61	2.45	12,546	61.9	130.0
"	4.27	16.04	67.43	12.26	2.15	12,773	73.3	125.5
California	17.36	38.41	28.76	15.47	2.96	8,530	32.1	158.3
"	12.77	26.16	45.56	15.51	2.28	9,474	39.6	132.6
Illinois	11.35	34.62	40.63	13.40	4.76	10,733	45.5	168.0
"	10.08	32.71	38.26	18.95	4.15	9,958	41.5	120.2
Indiana	11.13	35.11	46.78	6.98	1.64	12,031	55.7	154.7
"	11.53	34.80	40.44	13.23	3.11	10,924	55.6	131.9
Indian Terr.	9.00	33.96	40.68	16.36	4.12	11,392	56.4	161.1
" "	5.00	36.51	49.98	8.51	1.43	12,787	51.6	159.2
Iowa	16.69	31.42	31.19	20.70	5.50	8,735	48.5	160.2
Kansas	4.35	31.97	52.43	11.25	3.00	12,836	60.1	167.2
"	4.23	31.49	54.09	10.19	3.18	12,967	66.0	128.9
Kentucky	4.49	36.82	55.28	3.41	0.51	13,747	64.0	176.0
"	8.47	35.24	46.81	9.48	3.60	11,986	55.0	153.7
Massachusetts	49.80	27.27	10.88	12.05	0.34	4,241	25.8	166.6
Missouri	11.60	35.28	38.28	14.84	4.56	10,505	55.7	140.0
"	11.60	35.28	38.28	14.84	4.56	10,505	40.5	135.6
Montana	8.56	32.36	45.69	13.39	0.54	10,685	43.2	181.5
"	11.40	34.55	43.31	10.74	1.72	10,575	45.2	127.7
New Mexico	1.79	31.32	51.40	15.49	0.66	12,542	63.9	159.6
" "	2.42	34.82	49.23	13.53	0.63	12,501	61.0	135.3
North Dakota	39.56	27.78	26.30	6.36	0.93	6,802	25.2	188.5
" "	38.92	25.54	30.15	5.39	0.48	6,739	32.6	145.0
Ohio	8.70	35.58	43.63	12.09	3.82	11,302	55.3	170.2
"	4.39	35.91	53.77	5.93	1.42	13,414	72.5	152.3
Pennsylvania	2.77	33.94	54.84	8.45	1.37	13,306	63.4	159.5
"	2.15	35.01	55.18	7.66	1.60	13,921	64.2	126.6
Tennessee	3.40	37.58	54.27	4.75	0.83	13,882	77.6	167.9
"	3.55	26.00	49.88	20.57	0.76	11,621	65.4	133.3
Texas	32.20	30.11	28.82	8.87	0.88	7,603	31.9	171.8
"	34.08	33.15	25.32	7.45	0.49	7,448	.....	156.1
Utah	5.83	42.46	47.05	4.66	0.57	13,212	59.3	171.4
Virginia	2.36	36.40	55.44	5.80	0.67	14,080	.....	169.0
"	4.51	22.77	62.64	10.08	1.59	13,351	78.3	138.1
Washington	4.01	34.61	47.49	13.89	0.38	12,218	58.1	168.6
"	16.02	33.27	36.81	13.90	0.59	9,634	38.2	144.1
West Virginia	3.83	34.34	53.61	8.22	0.62	13,288	54.4	171.6
" "	2.91	11.81	57.19	28.08	0.54	10,545	76.8	106.3
Wyoming	18.26	37.18	41.82	2.74	0.47	10,460	.....	171.8
"	8.63	36.81	32.83	21.73	4.47	9,853	41.7	146.6

anthracite, charcoal, or coke. Mixed with hydrocarbon vapors, added to enrich it, or which may have been decomposed with the aqueous vapor, it is used as illuminating gas in a great number of cities in America. It is also used for heating and for gas-

engines. Mixed with producer gas, it has become a powerful means of heating, especially where high temperatures are wanted.

Water gas contains but little nitrogen; this is its main distinction from producer gas, and that which gives it a special value from the point of view of economical heating.

Aqueous vapor and carbon when submitted to a high temperature, produce carbon monoxide and hydrogen. Theoretically, these are free from nitrogen; but there is always present a small percentage due to various causes. In the air gas producer 12 kilograms of carbon and 16 kilograms of oxygen (atomic weights) unite to form 28 kilograms of carbon monoxide. On the other hand, 12 kilograms of carbon and 18 kilograms of water form 28 kilograms of carbon monoxide and 2 kilograms of hydrogen. Then 1 kilogram of carbon furnishes 2.5 kilograms of gas composed of carbon monoxide and hydrogen.

One kilogram of hydrogen has a calorific value of 29,042 calories.* This also is the quantity of heat necessary to decompose the water; in the case of the water gas generator these calories are formed by the carbon burned. The 12 kilograms of carbon will have to furnish, then, the heat necessary to decompose 18 kilograms of water; that is,

$$2 \times 29{,}042 = 58{,}084 \text{ calories.}$$

But 12 kilograms of carbon, in burning, generate only

$$12 \times 2473 = 29{,}676 \text{ calories.}$$

To decompose the water, then, there is a shortage of

$$58{,}084 - 29{,}676 = 28{,}408 \text{ calories}$$

for 2 kilograms of hydrogen, or 14,204 calories for 1 kilogram. The heat must be furnished by an external source. In other terms, to gasify 1 kilogram of carbon there must be supplied

$$14{,}204 \div 6 = 2367 \text{ calories.}$$

The heat necessary for the decomposition of the water is actually taken from that of the preparatory period of the air

* Water being considered as vapor.

gas producer, which makes a loss of one-third of the total calories. In burning the water gas made under these conditions we utilize a part of the heat which would have been lost by the air gas producer only.

The decomposition of water by carbon is not as simple as would appear from the equation

$$H_2O+C=CO+H_2.$$

The lower portion of the fuel of the gas producer burns to carbon dioxide on account of air being present; in the upper portion the reaction takes place between the gaseous products formed in the lower portion and the heated carbon. The carbon dioxide is then in contact with the heated carbon and is reduced to carbon monoxide:

$$C+CO_2=2CO.$$

Thus, the reaction with the water would be

$$5H_2O+3C=2CO_2+CO+10H;$$

carbon dioxide being reduced to carbon monoxide in the final reaction, as in the case with the air gas producer.

Nine kilograms of aqueous vapor and 6 kilograms of carbon produce 1 kilogram of hydrogen and 14 kilograms of carbon monoxide, that is, a mixed gas is produced containing about one-half its volume of each gas.

One cubic meter of hydrogen weighs 85.5 grams, and a cubic meter of carbon monoxide, 1194 grams. Then the volumes occupied by each gas would be 11.69 for hydrogen and 11.13 for carbon monoxide, or 51.23 per cent of hydrogen and 48.77 per cent of carbon monoxide.

From the foregoing account, it will be seen that the intermittent flow is a cause of great loss of heat in the working of the water gas producer; but when a gas is wanted solely for heating at high temperatures, it may be obtained by a mixed system working continuously. The producer is filled with a mixture of air and steam, the air being employed in the proper proportion to keep up the heat necessary, or, in other words, to furnish by the combustion of part of the carbon, the number of calories necessary to the gasification of the remainder.

CALORIFIC VALUE OF EUROPEAN PRODUCER AND WATER GAS

Name or Location.	Hydrogen.	Methane.	Ethylene.	Illuminants.	Carbon Dioxide.	Carbon Monoxide.	Oxygen.	Nitrogen.	Calories, per Cubic Meter.	B.T.U. per Cubic Foot.	Authority.
Dowson Gas from Anthracite coal.	17.6	....	....	....	5.9	29.4	....	47.1	.....	146	Pfeiffer
" " " " "	17.0	....	....	2.0	6.0	23.0	....	52.0	1363	140	Schilling
" " " " "	18.4	....	....	0.6	7.2	26.8	....	47.0	1313	144	M. Witz
Dowson Gas from Bituminous coal.	18.2	....	....	1.0	9.0	18.2	....	53.7	1346	108	"
" " " " "	21.9	....	....	0.7	4.4	45.9	....	50.7	1015	109	"
Anthracite	18.8	....	4.10	....	1.60	21.30	....	53.0	1018	164	"
Beure-Lecauchez	20.0	....	....	4.0	5.0	21.0	....	49.5	1548	135	"
Dowson	.....	....	....	....	....	.....	....	.....	1262	156	Bueb-Dessau
"	16.5	....	....	1.0	4.8	25.4	....	51.1	1443	138	Witz
Frankfort, Germany	.....	....	....	....	....	.....	....	.....	1287	291	Bueb-Dessau
Siemens, coal	16.85	....	....	2.05	4.55	22.75	....	53.8	2723	139	" "
" "	8.6	....	2.4	....	5.2	24.4	....	59.4	1303	137	Ritchie
Siemens, St. Gobain	8.2	....	....	....	4.2	24.2	....	61.2	1283	145	Kraus
" (after removing tar)	5.8	3.2	0.2	2.2	4.0	22.8	5.6	63.4	1139	121	Campbell, A. I. M. E., xxii, 375
" at Cambria, Pa	12.0	....	....	....	4.0	28.0	....	56.0	1212	129	
" Midvale, Pa	8.3	....	4.7	....	5.7	15.4	....	65.9	1167	125	Trollius
" " "	6.0	....	3.0	....	1.5	23.6	....	65.9	1149	123	"
" " "	9.8	....	2.4	....	5.9	17.7	....	64.2	1038	111	"
Lecauchez, coke	10.83	....	1.10	....	3.57	21.76	....	61.36	1212	129	Witz
" dust, mixed	6.88	....	3.85	....	0.45	25.84	....	62.41	1362	145	"
" 12% volatile	20.00	....	3.50	....	5.00	21.00	....	49.50	1519	162	"
" dust, 14% volatile	12.27	....	4.62	....	2.96	22.91	....	55.62	1535	163	"
" 41% volatile	11.00	....	4.86	....	2.42	26.65	....	53.80	1542	163	"
Wilson, at Wrexham, England	0.90	0.91	....	....	6.91	29.58	....	61.7	1139	121	J. E. Stead
" " "	1.11	1.43	....	....	8.29	26.33	....	62.84	1201	128	"
" " "	11.55	1.45	....	....	4.00	26.89	....	58.11	1136	121	"
Phillips, Midvale	.....	....	1.4	....	3.9	27.30	....	67.4	940	100	Trollius
" "	8.7	....	1.2	....	8.7	20.0	....	61.4	972	104	"

CALORIFIC VALUE OF EUROPEAN PRODUCER AND WATER GAS—*Continued*

Name or Location.	Hydrogen.	Methane.	Ethylene.	Illuminants.	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.	Calories, per Cubic Meter.	B.T.U. per Cubic Foot.	Authority.
Phillips, Midvale	8.6	....	2.7	....	9.3	16.5	....	62.9	991	105	Troilius
" "	15.3	....	1.9	....	7.5	16.0	....	59.3	1115	119	"
" "	14.9	....	....	....	8.0	15.5	....	61.6	926	98	"
" "	28.7	....	1.0	....	6.1	22.3	....	41.9	1642	175	"
Scotch	0.9	....	....	....	21.7	29.24	....	48.2	946	101	J. L. Bell
Askam, England	0.14	....	....	....	13.47	33.80	....	52.59	859	92	"
Cleveland, England	0.06	....	....	....	14.32	27.03	....	58.84	669	72	"
Mond	27.2	....	1.8	0.4	17.0	11.0	....	42.5	1468	157	Ritchie
Kitson	1.5	....	....	....	1.5	34.0	....	63.0	1495	160	"
McKenzie	14.5	19.2	....	16.2	2.2	7.9	1.1	38.9	5280	565	W. A. Noyes
Gas from Wood	0.5	2.9	0.6	....	11.5	28.4	....	56.1	1385	145	Anonymous
" " Sawdust	0.8	2.3	0.3	....	15.1	26.1	....	55.4	1380	144	"
" " Peat	0.9	2.7	0.4	....	12.1	27.2	....	56.7	1291	138	"
" " Coal	0.65	2.5	0.45	....	7.35	28.0	....	61.0	1300	139	"
" " Wood	0.7	....	....	....	11.8	34.5	....	55.2	1156	124	Thwaite
" " Wood charcoal	0.2	....	....	....	0.8	34.1	....	64.9	1120	119	"
" " Peat	0.5	....	....	....	14.0	22.4	....	63.1	547	58	"
" " Coke	0.1	....	....	....	1.3	33.8	....	64.8	1131	121	"
Furnace gas from down comer	2.3	1.0	....	....	12.4	25.8	....	58.5	2561	274	Sweetser
" " "	1.2	1.2	....	....	10.2	29.0	....	58.4	2505	268	"

NATURAL GAS

The natural gas output in the United States has attracted considerable attention since 1875, and especially since 1880. This gas always accompanies petroleum, although petroleum does not always accompany the gas. The wells are situated in various portions of New York, Pennsylvania, Ohio, Indiana, West Virginia, Kentucky, Tennessee, Colorado, California, and also in numerous locations in Canada.

Natural gas is not of a constant or uniform composition, varying very much according to the locality from which it is taken. The individual constituent gases vary between wide limits, hydrogen at some places being almost absent, while at others it is as high as 35 or 40 per cent. Marsh gas is in every case the principal constituent, but this runs down as low as 40 per cent in some analyses. Nitrogen is sometimes absent, and when present in large amounts, it is supposable that the gas analyzed was contaminated with atmospheric air.

The Ohio and Indiana fields yield gas of nearer a uniform composition than any of the others. The following table is typical:

ANALYSES OF OHIO AND INDIANA NATURAL GAS

	Ohio.			Indiana.		
	Fostoria.	Findlay.	St. Mary's.	Muncie.	Anderson.	Kokomo.
Hydrogen	1.89	1.64	1.94	2.35	1.86	1.42
Marsh gas	92.84	93.35	93.85	92.67	93.07	94.16
Olefiant gas	0.20	0.35	0.20	0.25	0.47	0.30
Oxygen	0.35	0.39	0.35	0.35	0.42	0.30
Carbon monoxide	0.55	0.41	0.44	0.45	0.73	0.55
Carbon dioxide	0.20	0.25	0.23	0.25	0.26	0.29
Nitrogen	3.82	3.41	2.98	3.53	3.02	2.80
Hydrogen sulphide	0.15	0.20	0.21	0.15	0.15	0.18

In addition to the difference in composition in different localities, the composition of the gas varies considerably from time to time in each well. This is shown by the following analyses made at different times within a period of three months from a well at Pittsburgh, Pa.:*

*This statement does not agree with the conclusions reached by the Bureau of Mines in regard to Pittsburgh gas. See the table on page 164.

ANALYSES OF PITTSBURGH NATURAL GAS

	1	2	3	4	5	6
Hydrogen	9.64	14.45	20.02	26.16	29.03	35.92
Marsh gas	57.85	75.16	72.18	65.25	60.70	49.58
Olefiant gas	0.80	0.60	0.70	0.80	0.98	0.60
Illuminants	5.20	4.80	3.60	5.50	7.92	12.30
Oxygen	2.10	1.20	1.10	0.80	0.78	0.80
Carbon monoxide	1.00	0.30	1.00	0.80	0.58	0.40
Carbon dioxide	0.00	0.30	0.80	0.60	0.00	0.40
Nitrogen	23.41	2.89	0.00	0.00	0.00	0.00

From the composition of the gas, it will be readily seen that it is a valuable source of heat, the calorific power reaching 10,000 calories or 1100 B.T.U. per cubic foot. It is used for domestic purposes, steam, glass making, iron mills, brick burning, and in numerous other ways, and until recently, used wastefully in all.

As compared with coal, 57.25 lb. of coal or 63 lb. of coke are about equal to 1000 cu.ft. of the gas. The actual equivalent in steaming or furnace work varies with the furnace, and probably with the people using it. Equivalent values of 14,000 to 25,000 cu.ft. per ton of coal are reported, and hardly any two users will give the same yield.

In all cases where this gas is used the chief claim made, in addition to those of gases generally, has been cheapness, and it has been sold without any regard to its actual value. A comparison of its value with that of other gases is given by McMillan in the Report of the Ohio Geological Survey, vol. vi, p. 544, as follows:

1000 ft. natural gas will evaporate.....893 lb. of water.
1000 ft. coal gas will evaporate .....591 lb. of water.
1000 ft. water gas will evaporate.....262 lb. of water.
1000 ft. producer gas will evaporate.....115 lb. of water.

The United States Bureau of Mines collected samples of natural gas as supplied to 25 cities in the United States and subjected them to chemical analysis and calorimetric determinations. The results are published in Technical Paper 109 from which the following table is condensed:

ANALYSIS AND CALORIFIC VALUE OF NATURAL GAS

Location.	CH_4	C_2H_6	CO_2	N_2	B.T.U. per Cubic Foot at 760 mm. Pressure.		Specific Gravity.
					0° C.	60° F.	
Texarkana, Ark	96.0	0.0	0.8	3.2	1022	967	0.58
Noblesville, Ind	86.8	6.2	0.8	6.2	1040	984	0.62
Leavenworth, Kans.	91.3	4.5	0.8	3.4	1066	999	0.60
Louisville, Ky.	77.8	20.4	0.0	1.8	1205	1143	0.66
Mansfield, La.	97.3	0.0	0.4	2.3	1066	1009	0.59
Joplin, Mo.	92.6	4.3	0.6	2.5	1066	1009	0.59
Alma, N. Y.	68.8	31.1	0.0	0.1	1312	1241	0.71
Buffalo, N. Y.	79.9	15.2	0.0	4.9	1134	1073	0.65
Cincinnati, Ohio.	79.8	19.5	0.0	0.7	1213	1147	0.65
Cleveland, Ohio	80.5	18.2	0.0	1.3	1196	1113	0.65
Marietta, Ohio.	73.2	25.6	0.0	1.2	1256	1188	0.69
Springfield, Ohio	80.3	14.7	0.0	5.0	1129	1068	0.65
Chelsea, Okla	75.4	17.7	0.3	6.6	1132	1071	0.67
Nowata, Okla.	95.2	0.0	1.3	3.5	1014	960	0.58
Pawhuska, Okla.	85.1	8.8	1.0	5.1	1070	1012	0.63
Oil City, Pa	67.6	31.3	0.1	1.1	1302	1232	0.71
Corsicana, Texas	98.0	0.0	0.7	1.3	1044	987	0.57
Dallas, Texas	50.6	10.9	0.1	38.4	742	702	0.77
Ft. Worth, Texas.	51.1	10.0	0.0	38.9	730	691	0.76

Pittsburgh natural gas was analyzed for a period of almost one year. The gas remained remarkably constant in composition although taken from many different wells.

The maximum, minimum and average calorific values of the several analyses, together with the corresponding composition, are as follows:

COMPOSITION AND CALORIFIC VALUE OF PITTSBURGH NATURAL GAS

U. S. Geological Survey, Technical Paper 109

	CH_4	C_2H_6	CO_2	N_2	B.T.U. per Cubic Foot at 760 mm.		Specific Gravity.
					0° C.	60° F.	
Maximum	78.7	20.4	0.0	0.9	1218	1152	0.66
Minimum	83.4	15.8	0.0	0.8	1182	1119	0.64
Average	80.6	18.6	0.0	0.8	1205	1140	0.65

The variation in the composition and calorific power of natural gas from different oil fields in exemplified by the table on page 165, from Bulletin No. 88 of the Bureau of Mines, which presents analyses of natural gases from oil fields located in every portion of the United States.

ANALYSES OF NATURAL GAS FROM VARIOUS LOCALITIES

Date.	Oilfields.	State.	CO_2	O_2	N_2	CH_4	C_2H_6	Heating Value, B.T.U. per Cu.Ft.
1909	Santa Maria	Cal.	15.5	0.2	1.4	62.7	20.2	1044
1910	Torrey	Cal.	6.8	0.0	3.4	54.2	35.6	1240
1910	Coalinga	Cal.	11.1	0.0	0.9	88.0	0.0	937
1909	McKittrick	Cal.	30.4	0.0	2.4	66.2	1.0	724
1909	W. Los Angeles	Cal.	1.0	0.1	5.2	91.0	2.7	1019
1909	Sunset	Cal.	10.5	0.0	1.8	87.7	0.0	934
1909	Fullerton	Cal.	1.7	0.0	2.1	86.7	9.5	1100
1909	Kern River	Cal.	6.5	0.0	1.2	84.3	8.0	1047
1911	Clarion	Pa.	0.0	0.0	1.1	96.4	2.5	1073
1911	Forest	Pa.	0.0	0.0	1.0	70.8	28.2	1279
1911	Clarion	Pa.	0.0	0.0	1.7	80.5	17.8	1189
1911	Butler	Pa.	0.0	0.0	0.9	53.3	45.8	1420
1911	Armstrong	Pa.	0.05	0.0	1.45	81.6	16.9	1184
1912	Hogshooter	Okla.	1.1	0.0	4.6	94.3	0.0	1004
1912	Creek	Okla.	2.4	0.0	1.8	64.1	31.7	1273
1912	Barren	Ky.	2.5	0.0	1.3	23.6	69.7	1548
1912	Barren	Ky.	2.6	0.0	5.1	44.1	48.2	1367
1910	Grand	Utah	3.6	0.0	5.6	90.8	0.0	967
1910	Grand	Utah	3.5	0.0	6.5	90.0	0.0	969
1911	Crawford	Pa.	0.0	0.0	2.3	6.6	91.1	1765
1910	Tillamook	Oreg.	0.1	0.0	97.9	2.0	0.0	21
1910	Churchill	Nev.	1.3	0.0	3.1	95.6	0.0	1018
1914	Cuyahoga	Ohio	0.0	0.0	1.3	80.5	18.2	1196
1914	Franklin	Ohio	0.0	0.0	1.5	80.4	18.1	1193
1914	Hamilton	Ohio	0.0	0.0	0.7	79.8	19.5	1213
1914	Erie	N. Y.	0.0	0.0	4.9	79.9	15.2	1134
1914	Jasper	Mo.	0.6	0.0	2.5	92.6	4.3	1066
1914	Jefferson	Ky.	0.0	0.0	1.8	77.8	20.4	1205
1914	Dallas	Tex.	0.1	0.0	38.4	50.6	10.9	742
1914	Nowata	Okla.	1.3	0.0	2.2	96.5	0.0	1038

OIL GAS

There are several processes for producing gas from oil, usually petroleum or its derivatives. Some of them decompose the oil by means of heat alone, while others use steam, or steam and air together. The most successful pure oil process is the Pintsch; this is used extensively in the large cities of Europe and America to obtain gas for illuminating cars on railways. The gas is made by allowing the oil to fall drop by drop on a strongly heated surface. Complete decomposition occurs, and a gas of high candle-power is formed. This is collected, and after compression supplied to the consumers. It loses some 20 per cent of the illuminating power during compression. As a source of heat, its use is, so far, very limited.

The Archer gas process is somewhat similar to the Pintsch, but the products of decomposition are generated at a compara-

(*Continued on page 168.*)

ANALYSES AND CALORIFIC VALUE OF ENGLISH NATURAL GAS

Name or Location.	Sp. Gr.	Hydrogen.	Methane.	Illuminants.	Carbonic Acid.	Oxygen.	Nitrogen.	Air.	Calories per Cubic Meter.	B.T.U. per Cubic Foot.	Authority.
Bensham seam, Wallsend	0.6024	....	91.00	....	....	.....	.....	9.00	9134	976	Turner
" " "	.....	....	77.50	....	1.30	.....	21.10	.....	7779	832	Playfair
Pipe from Wallsend	.....	....	92.80	....	0.30	0.60	6.90	.....	9315	996	"
Below Bensham, Hebburn	.....	....	91.80	....	0.70	0.90	6.70	.....	9215	985	"
" " " (30 d. later)	.....	....	92.70	....	0.90	.....	6.40	.....	9304	995	"
Bensham, Hebburn	.....	....	86.50	....	1.60	.....	11.90	.....	8682	928	"
" Jarrow	0.6381	....	81.50	....	....	.....	.....	18.50	8132	869	Turner
" "	.....	....	83.10	....	2.10	0.40	14.20	.....	8331	890	Playfair
Five quarter, Jarrow	.....	....	93.40	....	1.70	.....	4.90	.....	9375	993	"
Low Main, Jarrow	.....	3.00	79.70	....	....	3.00	12.30	.....	8090	865	"
Same (deeper)	0.6209	....	89.00	....	....	.....	.....	11.00	8934	955	Turner
Yard Coal, Burraton	0.6000	....	91.00	....	....	.....	.....	9.00	9130	976	"
High Main, Killingworth	0.6196	....	85.00	....	....	.....	7.00	8.00	8530	912	"
Low Main, Killingworth	0.8226	....	37.00	....	....	.....	16.50	46.50	1317	397	"
" " "	0.6306	....	82.50	....	....	1.00	16.50	.....	8280	885	Graham
" " "	.....	....	66.30	....	4.03	.....	6.32	23.35	6652	711	Richardson
Main 100 fathoms, Hutton	0.7800	....	50.00	....	....	.....	27.00	23.00	5010	535	Turner
" 175 fathoms, Hutton	0.7470	....	50.00	....	....	.....	44.00	6.00	5019	536	"
" waste 125 fathoms, Penslier	0.9660	....	7.00	....	....	.....	11.00	82.00	703	75	"
Three-quarter, Townley	.....	....	56.17	....	6.00	.....	4.68	33.15	5638	602	Richardson
Two-quarter, Well-gate	.....	....	98.20	....	0.50	.....	1.30	.....	9857	1044	Playfair
" Gates-head	0.5802	....	94.20	....	....	1.30	4.50	.....	9457	1002	Graham
Cwm-Twrch	.....	....	19.30	....	0.80	15.50	63.80	.....	1937	206	Playfair

ANALYSES AND CALORIFIC VALUES OF EUROPEAN NATURAL GAS

Name or Location.	Hydrogen.	Methane, CH_4.	Ethylene, C_2H_4.	Illuminants.	CO_2	CO	Oxygen.	Nitrogen.	Calories per Cubic Meter.	B.T.U. per Cubic Foot.	Authority.
Pechelbronn, Germany	....	77.03	....	4.8	3.6	3.5	1.8	8.9	8539	908	Anonymous
Caspian Sea, Russia	....	92.24	....	4.26	3.50	...	...	....	9859	1062	"
Aspharon Peninsula, Russia	0.34	92.49	....	4.11	0.93	....	...	2.13	9859	1062	"
Blower in Mine, Wales	....	95.42	....	....	0.60	...	...	3.78	9578	1014	J. W. Thomas
Occluded gas, Wigan, Wales	....	80.69	4.75	....	6.44	...	...	8.12	8770	930	"

tively low temperature, and then superheated subsequently so as to make the gas permanent. This gas is used for metallurgical purposes, but its use for heating boilers is limited.

The other gases made with steam or steam and air have been advertised or pushed as fuel gases for several years. Many plants have been established and failed. A few of the most prominent are mentioned in the tables.

COKE OVEN GAS

The following table shows the calorific value of gas obtained from an Otto by-product coke oven. It is reproduced from a pamphlet published by the United-Otto Coke & Gas Co. of New York. The analyses of the coals from which the gases given in the table were made are not known.

ANALYSES OF ILLUMINATING GAS FROM UNITED-OTTO BY-PRODUCT OVENS, RETORT COAL GAS AND CARBURETTED WATER GAS

	Coke Oven Gas.	Retort Coal Gas.	Carburetted Water Gas.
Hydrocarbons	5.8	3.83	11.32
Methane	40.8	35.90	20.48
Hydrogen	37.6	48.49	29.35
Carbon monoxide	5.6	6.61	33.19
Carbon dioxide	3.7	0.12	0.17
Oxygen	0.4	0.00	0.32
Nitrogen	6.1	5.05	5.17
B.T.U. per cubic foot	730	669	719

OTHER GASES

Gas has been obtained from the destructive distillation of wood, rosin, fats and other materials. They have been used principally for illumination and seldom if ever for heat. They are now made only in exceptional cases.

Blast Furnace Gas. The waste gases from blast furnaces have come extensively into use for the generation of power by means of gas engines. They consist of a mixture of carbon dioxide, nitrogen and carbon monoxide, the latter being the combustible portion of the gas. The exact composition varies with the working of the furnace, a typical analysis by volume being

CO_2	7.08
CO	27.80
O	0.10
N	65.02

The calorific value of blast furnace gas is from 85 to 100 B.T.U. per cubic foot.

CHAPTER IX

THE COMBUSTION OF COAL

THE AIR REQUIRED FOR COMBUSTION OF COAL

THE amount of air required for the combustion of coal depends on the analysis of the coal, namely on the amount of carbon, hydrogen, oxygen and sulphur. The atomic weights of the several constituents and the proportions in which they combine with the oxygen of the air also have a bearing on the problem. Thus, the atomic weight of carbon is 12, and that of oxygen is 16. Each atom of carbon burned to carbon dioxide combines with two atoms of oxygen in the process. The weight of oxygen then required for the complete combustion of 1 lb. of carbon would be in the ratio of 12 : (2×16) or 2.66 lb. If the carbon is burned to carbon monoxide instead of to carbon dioxide, the one atom of carbon would combine with one of oxygen and the weight of oxygen required would be as 12 : 16 or 1.33 lb.

Similarly, the hydrogen will unite with the oxygen in the proportion of one atom of hydrogen to two atoms of oxygen, forming water. The atomic weight of hydrogen is 1 and therefore the weight of oxygen required for the combustion of one pound of hydrogen will be as (2×1) : 16, or 8 lb. of oxygen. As regards the sulphur, which burns to sulphurous acid, SO_2, its atomic weight is 32 and two atoms of oxygen are required for each atom of sulphur. The amount of oxygen required to burn 1 lb. of sulphur will be as 32 : (2×16) or 1 lb. of oxygen.

In practice, complete combustion is seldom attained with solid fuels, part of the carbon being burned to carbon monoxide instead of to carbon dioxide. Furthermore an excess of air over the theoretical requirements is necessary. This excess ranges in the neighborhood of 20 per cent. The calculation of the air required to burn 100 lb. of coal will be as follows: Assume the analysis of the coal to be 85 C, 8 H, 5 O, 1 S, 1 N. The oxygen

required for the combustion of the combustible constituents may then be tabulated, assuming that 5 per cent of the carbon is burned to carbon monoxide and that the remainder burns to carbon dioxide.

Carbon to CO_2	$0.95\times85\times2.66$	$=214.80$	lb. oxygen
Carbon to CO	$0.05\times85\times1.33$	$=5.65$	" "
Hydrogen to H_2O	8×8	$=64.00$	" "
Sulphur to SO_2	1×1	$=1.00$	" "
Total		285.45	

Of this total of 285.45 lb. oxygen, 5 lb. was supplied from the oxygen of the fuel. The remainder, 280.45 lb. must be supplied from the air. Air is a mechanical mixture of oxygen and nitrogen in the proportion, by weight, of 23.15 and 76.85 respectively. It also contains an insignificant quantity of carbon dioxide, which for the present purpose may be neglected. The amount of air that will be required theoretically to burn 100 lb. of the above coal then will be

$$280.45\div0.2315=1211 \text{ lb.}$$

Air at a temperature of 62 deg. Fahr. and a pressure of 29.921 in. of mercury weighs 0.07608 lb. per cubic foot. Therefore the volume of air required will be

$$1211\div0.07608=15{,}917 \text{ cu.ft.}$$

As an excess of 20 per cent will be needed, the total amount of air required will be

$$15{,}917\times1.20=18{,}236 \text{ cu.ft.}$$

The calculation may be somewhat simplified by using the proportion of air to oxygen by weight, 4.320. That is, for every pound of oxygen needed there will be required 4.320 lb. of air. Hence to supply 280.45 lb. of oxygen, there must be supplied

$$280.45\times4.32=1211.5 \text{ lb. of air.}$$

The amount of air utilized for combustion per pound of carbon may be determined from the analysis of the flue gases as follows:

The analysis of the flue gas will show the respective percentages of carbon dioxide, oxygen, carbon monoxide and nitrogen. Bearing in mind that the atomic weight of carbon is 12 and of oxygen 16, $^{12}/_{44}$ or $^{3}/_{11}$ of the weight of the CO_2, and $^{12}/_{28}$ or $^{3}/_{7}$ of the CO will be carbon. If the percentage by weight of the several constituents of the dry flue gas be represented by their chemical symbols, then the weight of dry gas per pound of carbon will be

$$\frac{CO_2+CO+O+N}{^{3}/_{11}CO_2+^{3}/_{7}CO}=\frac{100}{^{3}/_{11}CO_2+^{3}/_{7}CO}.$$

If B is the percentage of carbon in the coal, then the dry gas per pound of coal will be

$$\frac{100B}{^{3}/_{11}CO_2+^{3}/_{7}CO}.$$

The relative densities of the several gases are

Carbon dioxide, CO_2	11
Oxygen, O	8
Carbon monoxide, CO	7
Nitrogen, N	7

If the percentage by volume of the several constituents of the dry flue gas are known the quantity of dry gas per pound of carbon may be found by multiplying each of the terms in the first formula above by the relative density of the constituent which it represents. Thus

$$\text{Dry gas per lb. of C}=\frac{11CO_2+8O+7CO+7N}{11\times{}^{3}/_{11}CO_2+7\times{}^{3}/_{7}CO}$$

$$=\frac{11CO_2+8O+7(CO+N)}{3(CO_2+CO)},$$

and the dry gas per pound of coal will be

$$B\left\{\frac{11CO_2+8O+7(CO+N)}{3(CO_2+CO)}\right\}.$$

The carbon in the gases is obtained from the fuel. The nitrogen is obtained from the air with the exception of a rela-

tively small amount from the fuel. The oxygen comes from both the air and the fuel. Since the air consists of 76.85 per cent by weight of nitrogen or $3.32 \div 4.32$, the quantity of dry air required per pound of carbon can be determined from the gas analysis as follows: Let N be the percentage by weight of nitrogen in the flue gas and n the percentage of this quantity due to the nitrogen in the coal. Then

$$\text{Dry air per lb. carbon} = \frac{7(N-n)}{3(CO_2+CO)} \times \frac{4.32}{3.32}.$$

The quantity of nitrogen represented by n is insignficant In the example cited in the first part of this chapter, the 280.45 lb. of oxygen theoretically necessary were supplied from the air. The quantity of nitrogen in the flue gas supplied from the air then would be

$$280.45 \times 3.32 = 931.09 \text{ lb.}$$

As an excess of 20 per cent of air was supplied the total nitrogen from the air in the flue gas would be $931.09 + 186.22 = 1117.31$ lb. The nitrogen supplied from the coal itself is but 1 lb., and therefore the value of n in the example cited is

$$100\{1 \div (1117.31+1)\} = 0.089 \text{ per cent.}$$

Air Supply Required for Different Grades of Coal. William Kent* gives the following formula for determining the amount of air required to burn different kinds of coal whose ultimate analysis is known, based on an excess of air of 50 per cent above the theoretical amount required for complete combustion.

$$\text{Lb. air per lb. coal} = 1.5 \times [11.52C + 34.56(H - {}^1/_8O)],$$

C, H and O being respectively the carbon, hydrogen and oxygen in 1 lb. of coal, or the percentage divided by 100. Dividing the result by combustible or by the carbon in 1 lb. of coal gives the pounds of air required per pound combustible or per pound carbon.

Calculations of the air supply for the several varieties of coal whose analyses are given in the following table, give the results there shown.

* Steam Boiler Economy, p. 36.

ULTIMATE ANALYSIS OF COAL DRIED AT 105° C.

Kind of Coal.	Anthracite.	Semi-anthracite.	Semi-bituminous.	Bituminous, Pa.	Bituminous, Ohio.	Lignite, Texas.	Crude Oil, Texas.
Carbon	76.86	78.32	86.47	77.10	75.82	64.84	84.8
Hydrogen	2.63	3.63	4.54	4.57	5.06	4.47	11.6
Oxygen	2.27	2.25	2.68	6.67	10.47	16.52	1.1
Nitrogen	0.82	1.41	1.08	1.58	1.50	1.30	0.8
Sulphur	0.78	2.03	0.57	0.90	0.82	1.44	1.7
Ash	16.64	12.36	4.66	9.18	6.33	11.43	
POUNDS OF AIR REQUIRED FOR COMBUSTION							
Per lb. dry coal	14.50	15.27	17.12	15.26	15.04	12.45	
Per lb. combustible	17.39	17.42	17.96	16.81	16.05	14.06	20.60
Per lb. carbon	18.86	19.50	19.40	19.65	19.84	19.21	24.29

Having the proximate analysis only, a close approximation to the number of pounds of air required per pound of combustible, in order to have the air supply 50 per cent in excess, is as follows:

	Pounds.
Anthracite and semi-anthracite	17.4
Semi-bituminous	18.0
Bituminous, Pennsylvania	17.0
Bituminous, Ohio	16.0
Lignite, Texas	14.0
Crude oil, Texas	20.6

CHAPTER X

CALORIFIC POWER OF COAL BURNED UNDER A STEAM BOILER

A BOILER trial or boiler test is a measure on a large scale of the heat obtained by burning the fuel used under the conditions of practice. Instead of the calorific value of the coal or other fuel being found in B.T.U. or calories, it is given as the evaporation of a certain number of pounds of water from and at 212 deg. Fahr. This may be as the evaporation per pound of coal "as fired," that is with the moisture and ash not taken into account. It also may be given as the evaporation per pound of dry coal, and per pound of combustible.

The objects of boiler trials are: (1) To ascertain the quantity of water that will be evaporated by a given quantity of fuel, so that it may be compared with other fuels.

(2) To determine the evaporative power of the boiler under the existing conditions.

(3) To compare different methods of burning the fuel, such as different types of grates or stokers.

The two latter objects are the principal ones for which boiler trials are made. An evaporation test is a cumbrous method of determining the relative calorific power of different fuels, as there are too many conditions that cannot be brought under absolute control, and the information can better be obtained in the laboratory with the calorimeter. The calorimetric tests, however, will not tell what the efficiency of the fuel will be when burned under the conditions of practice. The arrangement of the boiler plant, the method of firing, the air supply, the rate of driving and a number of other factors all have an influence on the amount of heat that the boiler will absorb from each pound of coal burned, and the magnitude of these several influences can be ascertained only by means of the boiler test. The boiler test will not only give information as to the evaporative power of the fuel under

the existing conditions, but will also show the distribution of the losses of heat, as in the flue gases, ash, etc.

A boiler test is made by weighing the coal used by the boiler during a certain length of time, preferably not less than eight hours, and measuring or weighing the amount of water fed to it during the same period. Observations are made at frequent intervals of temperatures of the feed water, steam, flue gases, and atmosphere, and of the pressure of the steam and the force of the draft. From these data the performance of the boiler can be calculated. The test should be carried on according to the boiler test code of the American Society of Mechanical Engineers, which is abstracted elsewhere in this work. Complete directions are there given as to the steps necessary and the precautions to be observed and the reader is referred to it for further information on this subject.

Coal Analyses. The composition of the coal used can be expressed either by a proximate or an ultimate analysis. The proximate analysis determines the percentage of moisture, ash, volatile matter and fixed carbon in the coal. The ultimate analysis resolves the coal into the percentages of carbon, hydrogen, oxygen, nitrogen, and sulphur contained in it, irrespective of the manner in which they are combined with each other. For all practical purposes the proximate analysis furnishes the necessary information in regard to the calorific value of the coal. The method of making it will be briefly described. For methods of making ultimate analyses the reader is referred to works on chemistry.

In making a proximate analysis, a small quantity, say one or two grams, which is a representative sample of the entire lot of coal is weighed into a perfectly dry crucible. The moisture is then driven off by heating the coal to a temperature of from 240 to 280 deg. Fahr. Early experimenters held that to heat it above 212 deg. Fahr. drove off a part of the volatile matter, but it has been shown by Kent and Carpenter* that there is no loss of volatile matter at temperatures below 350 deg. Fahr. with bituminous and semi-bituminous coals, and at temperatures of less than 700 degrees Fahr. with anthracite. The moisture having been driven off, the crucible is closed and heated to a red heat until there are no more fumes or gases given off. The weight of fuel remaining in the crucible is then noted. The fixed carbon is determined by

* Steam Boiler Economy, p. 582.

heating the residue in the crucible, the cover being removed, until nothing remains but the ash. In order to consume all the fixed carbon it may be necessary to introduce a gentle stream of oxygen into the crucible while the heat is being applied. The weight of the residue is again noted and recorded as ash. The difference between the weight of the residue after the volatile matter has been driven off, and the weight of the ash is the weight of the fixed carbon. The difference between the weight of the dry coal and that of the residue after driving off the volatile matter is the weight of the volatile matter. The difference between the weight of the original sample and of the dry coal is the weight of the moisture. These various weights are then expressed as percentages of the weight of the original sample. The completion of each of the several operations of determining moisture, volatile matter and fixed carbon can be ascertained by weighing the sample several times in succession, applying the heat between each weighing. When the weight becomes constant, the operation can be regarded as finished.

In determining the moisture in the coal it is recommended that a large sample be used, weighing from 5 to 50 lbs. The use of a sample of one or two grams is apt to give incorrect results in regard to moisture, for the reason that in certain coals the moisture is held in the coal by capillary attraction, and when the coal is pulverized prior to its introduction to the crucible some of this moisture will evaporate into the atmosphere before the coal can be weighed. By using the large sample, the coal can be dried in the condition in which it is received, and this loss due to air drying avoided. The retention of moisture by capillary attraction is also the reason for heating the coal to 250 deg. Fahr. or more, as moisture so retained will not be driven off at a temperature much below this.

HEATING VALUE OF CONSTITUENTS OF COAL

Commenting on the heating value of the various constituents of the coal William Kent* writes:

Coal is composed of four different things, which may be separated by proximate analysis, viz., fixed carbon, volatile hydro-

* Steam Boiler Economy, p. 54.

carbon, ash, and moisture. In making a proximate analysis of a weighed quantity, such as a gram of coal, the moisture is first driven off by heating it to 250 or 280 deg. Fahr., then the volatile matter is driven off by heating it in a closed crucible to a red heat, then the carbon is burned out of the remaining coke to a white heat, with sufficient air supply, until nothing is left but the ash.

The fixed carbon has a constant heating value of about 14,600 B.T.U. per pound. The value of the volatile hydrocarbon depends on its composition, and that depends chiefly on the district in which the coal is mined. It may be as high as 21,000 B.T.U. per pound, or about the heating value of marsh-gas, in the best semi-bituminous coals, which contain very small percentages of oxygen, or as low as 10,000 B.T.U. per pound, as in those from some of the Western States, which are high in oxygen. The ash has no heating value, and the moisture has in effect less than none, for its evaporation and the superheating of the steam made from it to the temperature of the chimney-gases absorb some of the heat generated by the combustion of the fixed carbon and volatile matter.

The analysis of a coal may be reported in three different forms, as percentages of the moist coal, of the dry coal, or of the combustible. Thus, suppose one gram of coal is analyzed, and the first heating shows a loss of weight of 0.1 gram, the second of 0.3 gram, the third 0.5 gram, the remainder, or ash, weighing 0.1 gram, the complete report would be as follows:

	Per Cent of the Moist Coal.	Per Cent of the Dry Coal.	Per Cent of the Combustible.
Moisture	10		
Volatile Matter	30	33.33	37.50
Fixed carbon	50	55.56	62.50
Ash	10	11.11	
	100	100.00	100.00

The relation of the volatile matter and the fixed carbon in the last column of the table enables us to judge the class to which the coal belongs, as anthracite, semi-anthracite, semi-bituminous, bituminous, or lignite. Coals containing less than 10 per cent volatile matter in the combustible would be classed as anthracite, between 10 and 15 per cent as semi-anthracite, between 15 and 30 per cent

as semi-bituminous, between 30 and 50 per cent as bituminous, and over 50 per cent as lignitic coals or lignites.

The figures in the second column, representing the percentages in the dry coal, are useful in comparing different lots of coal of one class, and they are better for this purpose than the figures in the first column, for the moisture is a variable constituent, depending to a large extent on the weather to which the coal has been subjected since it was mined, on the amount of moisture in the atmosphere at the time when it is analyzed, and on the extent to which it may have accidentally been dried during the process of sampling.

The heating value of a coal depends on its percentage of total combustible matter, and on the heating value per pound of that combustible. The latter differs in different districts and bears a relation to the percentage of volatile matter. It is highest in the semi-bituminous coals, being nearly constant at about 15,750 B.T.U. per pound. It is between 14,800 and 15,500 B.T.U. in anthracite, and ranges from 15,500 down to 13,000 or less in the bituminous coals, decreasing usually as we go westward, and as the volatile matter contains an increasing percentage of oxygen.

In 1892 the author deduced from Mahler's tests on European coals a table of the approximate heating value of coals of different composition, which is given, somewhat modified, below. (Trans. Am. Soc. M. E., vol. xx, p. 337.)

APPROXIMATE HEATING VALUE OF COALS *

Per Cent Volatile Matter in Coal Dry and Free from Ash.	Heating Value per Lb. Combustible.		Per Cent Volatile Matter in Coal Dry and Free from Ash.	Heating Value per Lb. Combustible.	
	B.T.U.	Calories.		B.T.U.	Calories.
0	14,580	8100	32	15,480	8600
3	14,940	8300	37	15,120	8400
6	15,210	8450	40	14,760	8200
10	15,480	8600	43	14,220	7900
13	15,660	8700	45	13,860	7700
20	15,840	8800	47	13,320	7400
28	15,660	8700	49	12,420	6900

The experiments of Lord and Haas on American coals (Trans. Am. Inst. Mining Engineers, 1897) practically confirm these figures for all coals in which the percentage of volatile matter is less than

40 per cent of the combustible, but for coals containing less than 60 per cent fixed carbon or more than 40 per cent volatile matter in the combustible they are liable to an error in either direction of about 4 per cent. It appears from these experiments that the coal of one seam in a given district, where the ratio of the volatile matter to the total combustible is uniform, has the same heating value per pound of combustible, within one or two per cent, but that coals of the same proximate analysis, and containing over 40 per cent volatile matter, but mined in different districts, may differ 6 or 8 per cent in heating value.

It will be noticed that the coals containing from 13 to 28 per cent of volatile matter in the combustible have practically the same heating value. This is confirmed by Lord and Haas's tests of Pocahontas coal. A study of these tests and of Mahler's indicates that the heating value of all the semi-bituminous coals, 15 to 30 per cent volatile matter, is within 1½ per cent of 15,750 B.T.U. per pound.

The heating value of any coal may also be calculated from its ultimate analysis, with a probable error not exceeding 2 per cent (except in the cases of cannel coal and some lignites, in which the error may be greater) by the following formula:

$$\text{Heating value per lb.} = 146\text{C} + 620\left(\text{H} - \frac{\text{O}}{8}\right),$$

in which C, H, and O are respectively the percentages of carbon, hydrogen, and oxygen. This formula is known as Dulong's. Its approximate accuracy is proved by both Mahler's and Lord and Haas's experiments, and any deviation of the calorimetric determination of any ordinary coal more than 2 per cent from that calculated by the formula is more likely to proceed from an error in either the calorimetric test or the analysis than from an error in the formula.

METHODS OF BURNING COAL

To obtain the maximum thermal value of the coal burned under a steam boiler it should be burned to carbon dioxide with as small an amount of excess air as possible. If the quantity of air admitted is in excess of the requirements heat will be lost by

being carried out with this air which will escape at the temperature of the flue gases. On the other hand, if there is deficiency in the air supplied, the carbon in the fuel will be burned to carbon monoxide generating 4450 B.T.U. per pound of carbon instead of 14,600 B.T.U. per pound of carbon as would be the case in burning to carbon dioxide. In practice, an excess of air of about 20 per cent over the theoretical requirements must be supplied to give the best results.

The ordinary boiler furnace with the grates placed directly under the boiler is satisfactory for the efficient burning of anthracite. It is, however, about as poor a contrivance as could be devised for the burning of bituminous and semi-bituminous coals. With anthracite in large sizes no great amount of skill is necessary to obtain good results and almost any kind of a furnace will be suitable. Hand firing is usually employed with anthracite and with the larger sizes, say down to egg, it is only necessary to keep the fuel bed level and regulate the draft and clean the fire at intervals of from 6 to 10 hours in order to obtain perfect combustion. With the smaller sizes of anthracite there is a tendency to choke the air passages through the coal on the grate and a thin fire, therefore, must be carried. This must be watched much more carefully to prevent the formation of air holes through which large quantities of excess air will pass, thus reducing the efficiency of boiler and furnace.

Bituminous and semi-bituminous coals should be burned in hot fire brick chambers so arranged that combustion will be complete before the gases of combustion are allowed to come in contact with the comparatively cold surfaces of the boiler. Upon the addition of soft coal to the fuel bed in the furnace large volumes of volatile gases are immediately distilled. These require for their combustion large quantities of excessively hot air. The addition of the fresh fuel, however, has choked some of the air passages through the fire, thus cutting down the air supply at the time when it should be materially augmented. Unless the gases of combustion are thoroughly mixed and brought in contact with whatever hot air may be passed through the fire, they will strike the surfaces of the boiler and become chilled below the point of ignition and pass out through the stack unconsumed. A large amount of heat can be lost in this manner. Incomplete

combustion of soft coal is indicated by dense smoke from the stack although a clean stack is not necessarily an indication of efficient combustion. A clean stack may indicate a large excess of air passing through the fire.

Soft coal can be burned without smoke providing that the gases are distilled from the coal at a uniform rate and that when so distilled they are brought into intimate contact with very hot air. The gases as they are distilled uniformly from the coal should then enter a fire brick chamber of either sufficient length to allow the gases to become entirely consumed naturally, or the chamber should be provided with such auxiliary mixing and baffling devices as will cause the gases to be artificially mixed before the exit of the chamber is reached.

With the ordinary method of spreading the coal over the fuel bed it is impossible to burn soft coal efficiently. The fresh coal chokes the air supply at the very instant it should be increased. Two methods of hand firing are in common use to overcome this difficulty, viz., the coking and the alternate method. In the coking method the fresh fuel is piled up on the front half of the fuel bed in the furnace, while the rear half of the grate has a level bed of half-burned coal upon it. An excess of air passes through the thin rear portion of the fire, being highly heated thereby. This hot air comes into contact with the gases distilled from the pile fuel in the front portion of the furnace and causes them to be consumed. When the gas has been pretty well distilled off from the pile at the front of the furnace the pile is pushed back and leveled over the rear portion of the fire and a fresh pile is built at the front. The disadvantages of this system are that it cannot be advantageously used with coals containing a large quantity of fusible ash and also that it is impossible to ascertain the condition of the rear portion of the fire. This system also involves a greater amount of labor and attention on the part of the firemen than does ordinary spread firing, and they, therefore, object to it.

The alternate method of firing consists of spreading fresh fuel over one-half of the grate either at the right or the left while the other side of the fire is allowed to burn thin. The gases distilled from the freshly fired coal come in contact with the excess of air passing through the thin portion of the fire and are con-

sumed. When the newly fired coal has burned to coke, the opposite side of the fire is covered with fresh fuel and the process is repeated. Special furnaces containing baffling and mixing devices facilitate complete combustion. With this system of firing successful prevention of smoke depends somewhat on the skill of the firemen, but more especially on the size of the combustion chamber and the provision of baffles or mixing walls, and the facilities provided for burning the gases before they come in contact with the heating surface of the boiler. With the alternate system of firing, the surface of the fire is available for inspection at all times and air holes can be detected immediately upon their formation.

A detailed description of furnaces and methods of firing adapted to all classes of fuel and every condition of service is given in Chapter VII of Steam Boiler Economy, by William Kent.

DISTRIBUTION OF THE HEAT OF COAL

When coal is burned under a steam boiler, the heat generated is partially absorbed by the water in the boiler, being converted into steam, and the remainder is lost up the stack and in radiation. If the combustion is perfect, all the heat energy in the fuel is accounted for in this manner. In practice, however, a portion of the fuel falls through the grates unburned, and this represents another source of loss.

If H represents the total heat units in a pound of coal, the distribution of it when burned under the boiler may be represented by the equation

$$H=S+G+A+R+C+U.$$

S being the heat absorbed in converting the water in the boiler into steam, G that escaping with the waste gases up the stack, A that contained in the unburned carbon in the ashes, R the radiation loss, C the heat in the carbon deposited as soot, and U that lost in the unburned hydrocarbons.

Heat in the Steam. The heat in the steam S (if it is not superheated) is the sum of the heat, h, required to raise the water in the boiler from the temperature of the feed water to the temperature corresponding to the pressure of the steam in the boiler and of

the latent heat of evaporation, H, at the temperature due to the pressure. Then $S=h+H$. If t is the temperature of the feed water and T that of the steam $h=T-t$. Thus if we have steam at an absolute pressure of 120 lb. per sq.in. (105.3 lb. gage pressure) its temperature is 341.3 deg. Fahr. Its latent heat of evaporation per pound is 877.2 B.T.U. (See table of properties of saturated steam, p. 242.)

If the feed water is at 60 deg. Fahr. $h=341.3-60=281.3$ B.T.U. Then $S=281.3+877.2=1158.5$ B.T.U. If the boiler evaporates 10 lb. of water per pound of combustible, the boiler would absorb 11,585 B.T.U.

Heat Lost in Waste Gases. The heat carried away by the waste gases is a complex quantity. It comprises:

(1) The heat carried away by the dry flue gases.

(2) The heat lost in the formation of steam from the moisture in the coal and from the burning of the hydrogen in the coal. To this should be added the heat required to superheat this steam to the temperature of the escaping gases.

(3) The heat lost in raising the temperature of the moisture in the air to the temperature of the escaping gases.

(4) The heat lost by the incomplete combustion of the fuel, such as the burning of carbon to carbon monoxide instead of to carbon dioxide and by the failure to consume all the hydrocarbons and hydrogen in the fuel.

Heat Carried Away by Dry Flue Gases. If T_f is the temperature at which the waste gases of combustion escape from the boiler and t_a is the temperature of the atmosphere, then all the air passing through the fire is raised T_f-t_a deg. A portion of the air in its passage is transformed to carbon dioxide, another portion, if combustion is imperfect, is transformed to carbon monoxide, and the balance is untransformed and appears in the analysis of the flue gas as nitrogen and oxygen. These various components of the waste gases have been elevated through T_f-t_a deg. and the amount of heat absorbed by each is the product of this difference and the weight of each gas and of its specific heat at constant volume.

Thus, if the analysis of the waste gases showed CO_2, 11.2 per cent, CO, 0.6 per cent, O, 7.5 per cent, N, 80.7 per cent and they escape at a temperature of 530 deg Fahr., the temperature of the

atmosphere being 70 deg. Fahr., the heat carried away by one pound waste of gas will be as follows:

	Percentage.		Specific Heat.		$Tf - ta$	
CO_2	0.112	×	0.217	×	460 = 11.08	B.T.U.
CO	0.006	×	0.248	×	460 = 0.68	"
O	0.075	×	0.2375	×	460 = 8.19	"
N	0.807	×	0.2438	×	460 = 90.50	"
					110.45	"

The table below, compiled by the Uehling Instrument Co., shows the heat carried away by dry chimney gases per pound of combustible.

HEAT CARRIED AWAY BY THE DRY CHIMNEY GASES PER POUND OF COMBUSTIBLE

Per Cent CO_2 in Gases.	Pounds Air per Pound Combustible.	Temperature of Chimney Gases, Deg. Fahr.							
		300°	350°	400°	450°	500°	550°	600°	650°
		Heat Wasted, Per Cent of Total Heat in Coal.							
21.0	12	5.2	6.2	7.3	8.7	9.5	10.5	11.6	12.7
16.8	15	6.0	7.6	9.1	10.3	11.6	13.0	14.3	15.6
14.0	18	7.2	9.1	10.7	12.2	13.9	15.4	17.0	17.9
12.0	21	8.7	10.5	12.3	14.2	16.0	17.8	19.5	21.0
10.0	24	9.9	12.0	14.0	16.1	18.2	20.3	22.4	24.4
9.3	27	11.1	13.5	15.7	18.1	20.4	22.7	25.0	27.4
8.4	30	12.4	14.9	17.4	20.0	22.6	25.0	27.8	30.4
7.6	33	13.5	16.3	19.2	22.0	24.7	27.6	30.5	33.2
7.0	36	14.7	17.8	20.8	23.9	27.0	30.0	33.0	36.6
6.5	39	15.9	19.2	22.5	25.8	29.2	32.4	35.7	39.0
6.0	42	17.1	20.6	24.7	27.7	31.3	34.8	39.4	42.0

Heat Carried by Moisture in the Coal. The heat carried away in the form of moisture converted into superheated steam is made up of two quantities. (*a*) The heat carried off in the moisture present in the coal as moisture; (*b*) the heat carried off in moisture formed by combustion of the hydrogen in the coal.

The heat carried off by moisture of the coal is the heat required to convert water into steam and the heat required to superheat it to the temperature of the escaping gases. The moisture will be raised from the temperature of the atmosphere to 212 deg. Fahr. and the B.T.U. required for this purpose will be $212 - t_a$. It will then be converted into steam at 212 deg. Fahr. at atmospheric

pressure and the heat required will be the latent heat of evaporation at 212 deg. Fahr. and atmospheric pressure or 970.4 B.T.U. It will then be superheated to the temperature of the flue gases and the heat required will be $(T_f-212)\times s$, s being the specific heat of superheated steam. The heat lost due to one pound of moisture in the coal, therefore, will be $(212-t_a)+970.4+(T_f-212)\times s$. If the coal contained 3 per cent moisture and the flue gas and atmospheric temperature were 530 and 70 deg. Fahr. respectively, then the heat lost per pound of fuel burned by reason of the moisture in the coal will be

$$\{(212-70)+970.4+(530-212)\times 0.463\}0.03=38.4 \text{ B.T.U.}$$

Heat Lost in the Formation of Steam. The heat lost due to the hydrogen in the coal being burned to water which is converted into steam and afterwards superheated to the temperature of the flue gases is the product of 9 times the percentage of hydrogen in the dry coal and of the sum of $\{(212-t_a)$ + the latent heat of evaporation + $(T_f-212)\times$ specific heat of superheated steam$\}$. If our dry coal contains 3 per cent of moisture and the atmospheric and flue temperatures are as before, the heat lost will be

$$0.03\times 9\{(212-70)+970.4+(530-212)\times 0.463\}=334 \text{ B.T.U.}$$

Heat Lost Due to Moisture in the Air. The moisture contained in the air is in the form of vapor and in its transformation to this state it has already absorbed the 970.4 B.T.U. latent heat, which therefore does not have to be supplied by the fuel. The fuel is required to raise the temperature of the vapor from that of the atmosphere to that of the flue gases.

The quantity of moisture in cubic feet in the air is determined by means of wet- and dry-bulb thermometers and humidity tables. The quantity of air used per pound of coal depends upon the tightness of the setting, the thickness of the fire, and several other factors which are discussed in Chapter X. Assuming for the moment that 20 lb. of air are required per pound of dry fuel and that the air contains 0.02 lb. of water per pound of dry air (60 per cent relative humidity) each pound of dry fuel will be required to evaporate 20 times 0.02 lb. of water into steam at atmospheric pressure and superheated to 530 deg. Fahr. The

heat required will be, flue gas and atmospheric temperatures being taken as 530 and 70 deg. Fahr., respectively

$$0.4\{(530-70)\times 0.463\} = 85.2 \text{ B.T.U.}$$

Loss Due to Formation of Carbon Monoxide. The heat lost due to the incomplete combustion of carbon to carbon monoxide instead of to carbon dioxide is the difference in heat of combustion or 10,150 latent B.T.U. multiplied by the percentage of carbon monoxide in the flue gases. If the coal contains 89 per cent of combustible and, as before, 3 per cent of hydrogen, and the ash and refuse amount to 12 per cent which includes 8 per cent, as shown by the analysis of the coal, then each pound of fuel burned will contain 0.77 lb. of carbon. Of this, 0.05 per cent will be burned to CO and the heat lost will be

$$0.05\times 0.77\times 10{,}150 = 390.7 \text{ B.T.U.}$$

Heat Lost as Soot. The soot in smoke consists of carbon with a trace of hydrogen. If it is considered as entirely carbon the error will be inappreciable. Knowing the volume of flue gas produced by the burning of one pound of fuel and the amount of carbon contained in them, as shown below, the heat lost can be determined by multiplying the volume of gas in cubic feet by the amount of carbon contained and the product by the calorific value of pure carbon or 14,500 B.T.U. Under the most favorable conditions for smoke production, the loss due to unconsumed carbon does not exceed one per cent and is usually less than half that amount.

Several methods have been devised for approximating the quantity of carbon contained in smoke. One of these is based on the amount of soot deposited upon a given surface, say one square foot, placed in the chimney. The soot deposits on the upper surface away from the direct current and after an exposure of a few hours is removed and weighed. Another method is to use smoked glasses of different degrees of density and ascertain what depth of color is necessary to make the smoke invisible. A third method and the one in general use is by means of the Ringelmann smoke chart.

The Ringelmann chart consists of four cards, ruled as shown

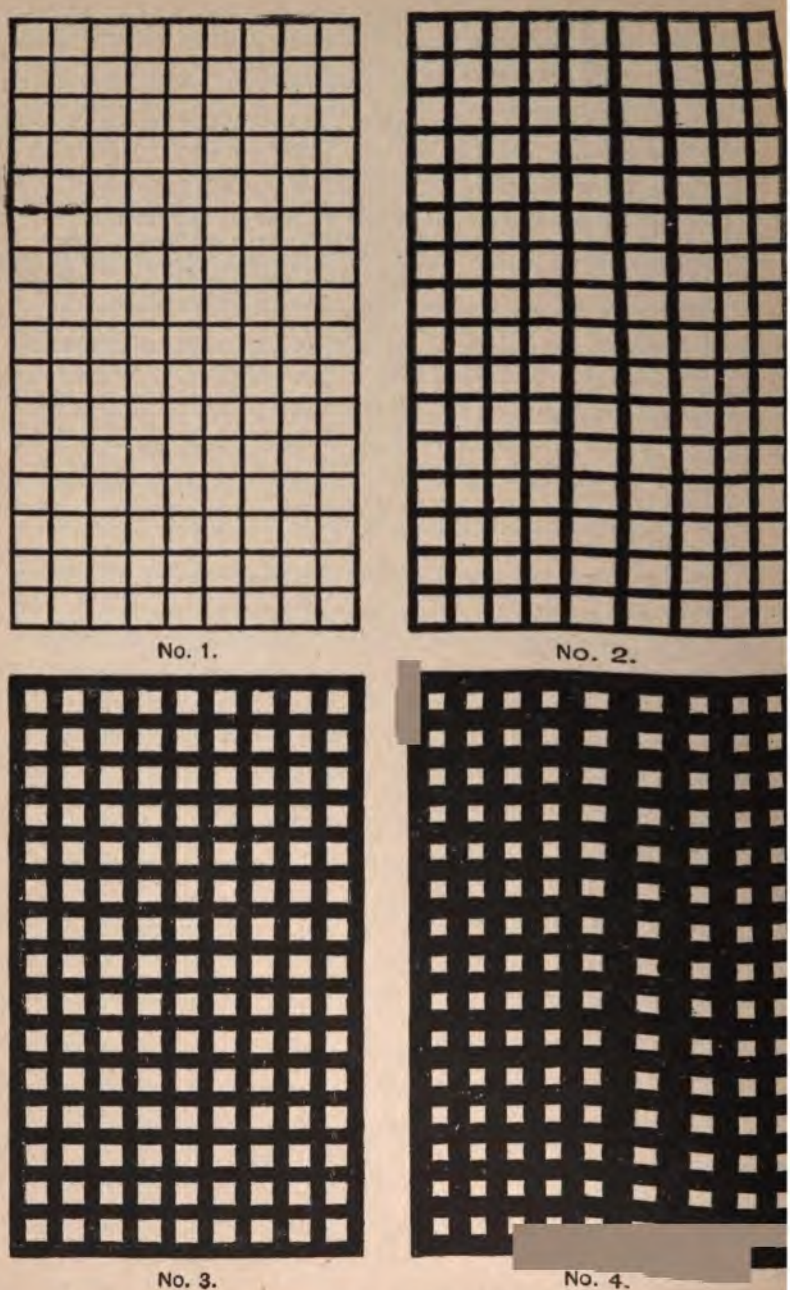

FIG. 36.—The Ringelmann Scale for Grading the Density of Smoke.

in Fig. 36, together with a card printed in solid black and another left entirely white. These are hung in a horizontal row about 50 ft. from the observer and as nearly as convenient in a line with the chimney. Under these circumstances the cards appear to

FIG. 37.

FIG. 38.

FIG. 39.

FIG. 40.

The Roberts Smoke Charts.

be different shades of gray, ranging from very light gray to almost black. The observer can easily determine which of the cards corresponds most nearly in color to the smoke coming from the stack. The color and time are recorded. The ruling on the card is given in the table on page 191.

The Roberts smoke chart, invented in 1912 by the then smoke inspector of the City of Cleveland, E. P. Roberts, is shown in Figs. 37 to 40. The charts consist of disks of cardboard having radial white lines on a black background. When the disk is revolved a series of tints appear corresponding to the density or

FIG. 41.

FIG. 42.

FIG. 43.

FIG. 44.

Appearance of the Roberts Smoke Chart when Spinning.

color of the smoke. The chart may be spun while supported on a bradawl or other convenient spindle. The several charts show the color of smoke corresponding to densities of 20, 40, 60, 80 and 100 per cent.

In 1895 Cohen and Russell made some experiments to deter-

RULING OF RINGELMANN SMOKE CHARTS

Card No.	Thickness of Lime.	Width of Spaces.
0	Pure White	
1	1 mm.	9 mm.
2	2.3	7.7
3	3.7	6.3
4	5.5	4.5
5	Solid Black	

mine the extent of pollution of the air by smoke from house fires burning coal. The coal used was from Yorkshire, Durham, and Wigan. The quantity of soot formed was determined by aspirating through a brass tube $^1/_2$ in. diameter connected with a glass tube of the same diameter and having a plug of cotton wool in one end. This plug was dried over sulphuric acid and the weight of the soot obtained. The results are given in the following table:

No.	Volume of Chimney-gases.	Weight of Soot.	Per Cent of Soot in Gases.	Per Cent of Soot to Carbon Burned.	Name of Coal.
	Liters.	Grams.			
1	218.0	0.0155	0.0073	6.9	
2	282.5	0.0267	0.0094	10.2	
3	249.5	0.0174	0.0070	8.0	" Silkstone Hards," Yorkshire
4	231.0	0.0228	0.0099	5.8	
5	164.5	0.0292	0.0177	9.3	
6	182.5	0.0219	0.0120	6.0	
7	175.0	0.0247	0.0141	7.7	" Haigh Moor Best," Yorkshire
8	278.5	0.0278	0.0100	5.1	
9	240.0	0.0243	0.0101	5.6	" Harvey Seam," Durham
10	230.5	0.0227	0.0098	4.8	" Hutton Seam "
11	262.0	0.0282	0.0108	7.1	" Best Deep Yard," Lancashire
12	230.0	0.0232	0.0101	5.1	" Best Arley " "
	2744.0	0.2844	0.0103	6.5	

It would seem that more reliable data could have been obtained had the carbon been collected on an asbestos plug and then burned, the carbon dioxide being collected. As originally performed the result of the test cannot be called carbon, as it manifestly contained considerable ashes, etc., which had been carried up the chimney. By burning off the soot in a combustion tube the actual content in carbon could have been obtained.

LOSS DUE TO UNBURNED COMBUSTIBLE GASES

Flue gas contains in addition to carbon monoxide, small quantities of other combustible gases, notably methane. Assume a flue gas analysis of

Carbon dioxide, CO_2	11.2	per cent
Carbon monoxide, CO	0.6	
Methane, CH_4	1.0	
Oxygen, O	7.5	
Nitrogen, N	79.7	
	100.0	

We have already calculated the loss due to unburned carbon monoxide. If, as before, 20 lb. of air are used per pound of combustible, and the fuel contains 89 per cent of combustible, each pound of fuel will generate 20.89 lb. of flue gas. Of this 0.2089 lb. will be methane, whose calorific value is 24,017 B.T.U. per pound. The heat lost due to the unburned CH_4 then will be

$$0.2089 \times 24{,}017 = 697.15 \text{ B.T.U.}$$

Distribution of the Heat. Assuming that our coal had a calorific value of 14500 B.T.U. per pound of combustible, the heat generated by its combustion with 20 lb. of air per pound of combustible would be distributed according to the foregoing calculations:

Heat absorbed by the boiler	11,585	B.T.U.
Heat carried away by dry flue gas	110.4	
Heat lost due to moisture in coal	38.4	
Heat lost due to hydrogen in coal	334.	
Heat lost due to moisture in air	85.2	
Heat lost due to formation of CO	390.7	
Heat lost in unconsumed CH_4	697.2	
Heat lost in unconsumed carbon in ash $0.04 \times 14{,}500$	580.0	
	13,836.4	
Radiation and unaccounted for	680.1	
	14,500	B.T.U.

CHAPTER XI

ANALYSIS AND MEASUREMENT OF THE PRODUCTS OF COMBUSTION

THE value and accuracy of the computations described in the foregoing pages depend upon the accuracy of the gas analysis, which in turn depends on the sample of gas analyzed. This should truly represent the total amount of gas sampled. Samples taken from the general current by means of an ordinary aspirator or an oil aspirator (p. 197) will usually do if drawn at a sufficient distance from the fire. If the gases have passed through a long flue, especially one with several bends, they are sufficiently mixed, and may be considered as a homogeneous gas. We must remember, however, that as we recede from the fire the infiltration of air, if not prevented, becomes greater. In careful experiments, the method to be described of fractionating a large volume is preferable.

GAS SAMPLER

In principle, a gas sampler consists of a falling-water aspirator, and a second mercury aspirator drawing a small fraction of the gases from the current of the first in a constant regular manner and keeping it in a mercury gas-holder, *A* (Fig. 45), which is a strong glass flask of 3 liters capacity, holding about 88 lb. of mercury. The gas-holder is connected by the tube *a* with the tube *o* for sampling the gas, the flask *A* and its accessories acting as a Mariotte flask. It is closed at the top by a stopper hollowed out conically below and having holes for two tubes, *a* and *b*. This hollowing is to permit filling without any air-bubbles. The tubes *a* and *b* have glass stopcocks, but the one in *a* may be omitted. The manometric tube *c* shows the pressure. Tube *d*, like *c*, passes through a rubber stopper, closing the horizontal tubulature of the gas-holder. This tube can be rotated in the stopper to the position shown, or to one 180 deg. from such position. The

flask is graduated on the side into millimeters. Tube *a* fits the hole of the stopper tightly, and can be moved up or down as desired to suit the quantity of gas in the flask. All joints are covered with paraffin, tube *a* being greased to facilitate movement.

Fig. 46 shows the gas sampling tube. It consists of a platinum cylinder, *rs*, 10 mm. (0.4 in.) diameter and 700 mm. (27.5 in.)

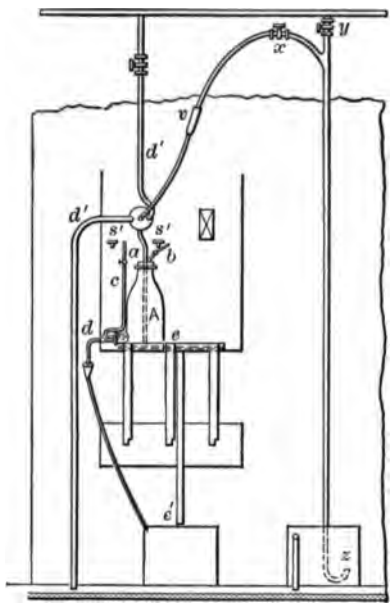

FIG. 45.—Gas Sampler.

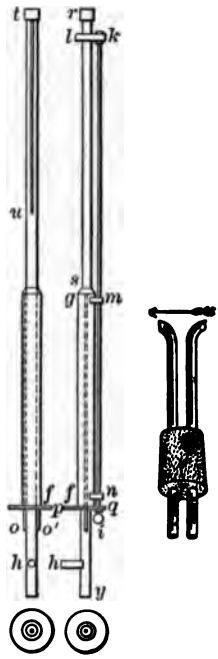

FIG. 46.—Sampler Tube.

long, having a longitudinal slot of several centimeters length. The end *r* is closed with a platinum cap; the end *s* is soldered to a copper tube, *sy*, passing into a Liebig condenser having two tubes, *oo'*, for the water. In most cases the platinum tube may be replaced without trouble by one of copper, or even iron, the platinum being necessary only when the gases are drawn at a temperature high enough to cause oxidation of the other metals. With iron or copper a portion of the oxygen is removed in the passage through the tube.

The tube *ry* is open at *y*, and has a side tube *h*. Aspiration is carried on through the opening in the platinum tube. A movable rod, *ik*, carrying a platinum scraper is attached to one end of the tube, and moves in the slot to clean it, as occasion requires, from soot, etc. The disk *p* serves to hold the cement used in fastening it to the stack or chimney, and prevents ingress

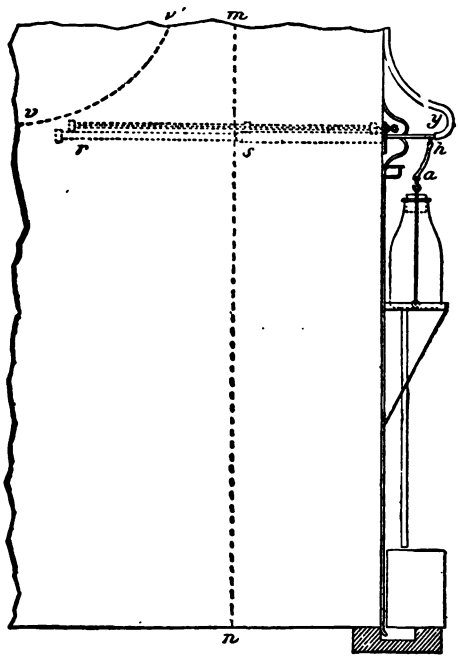

FIG. 47.—Gas Sampler.

of external air. The rod *mn* passes through a caoutchouc bearing fastened between the disks *p* and *q*.

Fig. 45 represents a front view of the apparatus. Fig. 47 represents a side view in elevation. The tube *ry* is introduced through an opening made for the purpose in the masonry, the part *rs* being exposed inside. The end *y* is connected with a lead pipe, *v*, by a rubber tube; this pipe is soldered to another one, *yz*. On opening the cock *y*, the water flows from a reservoir and empties at *z*. Suction in *yrs* should amount to several millimeters of mercury, and is regulated by the cocks *y* and *x* controlling the water-

flow, and also by the length of *yz*. The gas drawn in by *yvx* may be measured by collecting it at *z*, and should amount to 25 to 30 cu. in. per minute.

The gas-holder is supported by a piece of sheet iron with upturned edges forming a shelf. Any mercury spattered over or spilled is thus easily collected. The mercury tank is supported from the wall of the chimney in such position as to facilitate refilling the flask through a siphon. The tubes *dd'* serve to feed the condenser.

While the current is passing through *yr* a small quantity is drawn out by the tube *h*, and this should be so regulated by the cock *d* that only from $^1/_{250}$ to $^1/_{500}$ is collected.

Whenever the level of the mercury lowers, it shows a clogging in the slot, and it should be cleaned by moving the rod. This always indicates when cleaning is necessary, and it sometimes keeps clean for hours.

When a sufficient sample has been obtained the tube *d* is turned up and then the gas-holder can be carried away.

The method recommended by the American Society of Mechanical Engineers is to have a " box or block of galvanized sheet iron equal in thickness to one course of brick," and secure in it a series of $\frac{1}{4}$-in. gas-pipes, all alike at the ends and of equal lengths, in such manner that the open ends may be evenly distributed over the area of the flue. See Boiler Test Code, p. 223.

An arrangement recommended by Col. David P. Jones in his paper before the American Society of Naval Engineers, vol. x, p. 135, is shown in Fig. 48. The sampler is a large, wide-necked glass bottle closed with a cork having two glass tubes, one just entering the bottle, the other reaching nearly to the bottom. One of these tubes is connected with an iron pipe leading to the flue and extending well into it. The other tube is connected with any kind of an aspirator which works steadily. A water-jet exhaust, an engine-driven exhaust, or any similar apparatus will do. If not convenient to use an exhaust, the bottle may be filled with mercury and by making a siphon with the rubber tube attached to the long glass tube, the bottle can be gradually emptied of mercury and the gases to be sampled drawn in. If mercury cannot be had, water will do, but the result will not be as reliable since the water may dissolve some of the constituents of the gas.

The size of the bottle may be adapted to the quantity of gas aspirated, and by means of proper stop- or pinch-cocks adjusted to work slowly or fast.

Used in conjunction with the arrangement of sampling tubes recommended by the American Society of Mechanical Engineers, this apparatus forms a simple and satisfactory sampler. One great advantage in favor of this arrangement is the fact that it

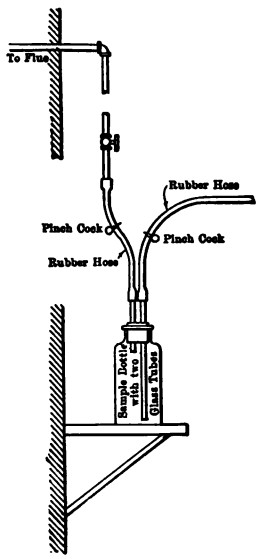

FIG. 48.—Jones Gas Sampler.

FIG. 49.—Oil Aspirator.

is easily made, all the portions of it being found in nearly every shop.

The *oil gas-holder* (Fig. 49) consists of a bottle tubulated at the bottom and connected with the supply of gas at the upper opening. It may contain some 600 cu. in., and is filled with water having on it a layer of 4 in. of oil. The water running out from the tubulature at the bottom draws the gas in at the top. The stopper at the top has two openings, through one of which passes a funnel-tube, through which water may be poured to expel the gas when portions of it are needed. The gas then passes out by the same tube through which it was drawn into the bottle.

With all kinds of aspirators or gas-holders especial care must be taken to prevent entrance of air into the flue gas after leaving the fire, since the correct analysis will show not only the quantity of unburned gases, but also the excess of air, and any mixture of outside air will vitiate the result and cause faulty deductions as to the working of the fire.

To prevent this, all joints in the masonry must be examined and repaired if necessary. In case of dampers, which must be used, the bearings can be made in stuffing-boxes. Generally, the gas can be sampled before it arrives at a damper, as the course of the boiler-flue is usually sufficient to cause a thorough mixing of the gases. In case there are several dampers, the first one may be dispensed with for the time being.

When the gases are taken quite near the fire, they must be drawn very slowly in order to gradually cool them down and avoid dissociation. In this case a stoneware tube may be used for suction. If this precaution is neglected the gases collected may be entirely different from those passing off at the chimney. Metal tubes are inadmissible, since they abstract oxygen, and hence cause a change in composition.

ANALYSIS OF THE GASES

The collected gases contain nitrogen, oxygen, carbon dioxide, carbon monoxide, hydrocarbons, and occasionally free hydrogen. To determine all these a eudiometric method must be used; but usually only the oxygen, carbon dioxide, and carbon monoxide are required. In normal combustion with sufficient air the quantity of hydrocarbons is trifling, and need not be considered. This occurs usually with a supply of air of 240 cu.ft. per pound of coal, and should produce a waste gas containing 10 to 14 per cent of carbon dioxide, in which case the unburned hydrocarbons amount to less than 1 per cent.

Flue gases are analyzed by first measuring a sample, usually 100 c.c., of filtered gas at atmospheric temperature and pressure, in an accurately graduated glass vessel, called a burette. This is kept at a uniform temperature by inclosing it in another glass vessel filled with water. The gas is then passed into a glass bulb or cylinder containing a chemical which absorbs one of the constituent gases, returning it to the burette, and measuring it again,

the difference being the volume of gas removed by the absorbent. This operation is repeated with different chemicals until all the constituent gases have been removed, except nitrogen, for which no absorbent has been found.

The absorbent usually employed for carbon dioxide is a concentrated solution of caustic potash. For oxygen a solution is made of 5 grams of pyrogallic acid in 15 c.c. of water added to a solution of 120 grams of caustic potash in 80 c.c. of water. In the Hempel apparatus slender sticks of phosphorus covered with water are sometimes used instead of the pyrogallic solution. For carbon monoxide the solution is made by dissolving 10.3 grams of copper oxide in 100 c.c. of concentrated hydrochloric acid. To insure greater accuracy the gas should be passed successively through two bulbs containing this solution. The order of analysis followed is always first CO_2, then O, then CO.

The Orsat Apparatus is a portable instrument contained in a wooden case with removable sliding doors front and back, as shown in its simplest form in Fig. 50. It consists essentially of a measuring tube or burette, three absorbing bottles or pipettes, and a leveling bottle, together with the connecting tubes and apparatus. The bottle and measuring tube contain pure water; the first pipette, sodium or potassium hydrate dissolved in three times its weight of water; the second, pyrogallic acid dissolved in sodium hydrate in the proportion of 5 grams of the acid to 100 c.c. of the hydrate; and the third, cuprous chloride. The manipulation of the instrument is as follows:

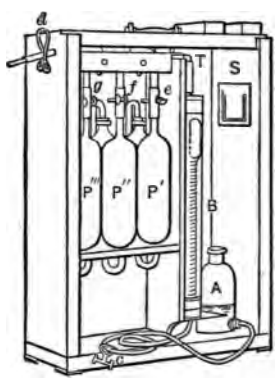

FIG. 50.—Orsat Apparatus.

After completely drawing out the air contained in the supply pipe, a sample of the gas is drawn into the measuring tube by opening the necessary connections and allowing the water to empty itself from the tube and flow into the bottle. The quantity of gas drawn in is adjusted to 100 c.c. By opening one by one the connections to the pipettes, and raising and lowering the water bottle, the sample is alternately admitted to and with-

drawn from the pipettes, and the ingredients one by one absorbed.

The first pipette absorbs CO_2; the second, O; and the third, CO. The quantity absorbed in each case is determined by returning the sample to the measuring burette and reading the volume. The percentage of CO_2 is read directly, being the first absorption. Those of the other two ingredients are the respective differences between the readings taken after successive absorptions.

Various modifications of this apparatus have been developed which enable analyses to be made with greater rapidity than with the form illustrated.

The Hempel Apparatus works on the same principle as the

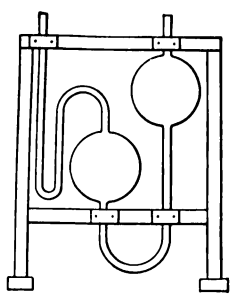

FIG. 51.—Hempel Pipette.

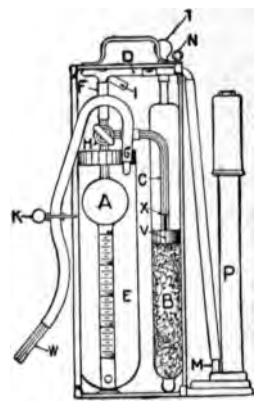

FIG. 52.—Nassau CO_2 Recorder.

Orsat, except that the absorption may be hastened by shaking the pipette bodily, bringing the chemical into most intimate contact with the gas. It is less portable and in some particulars it requires more careful manipulation than the Orsat.

The absorption pipettes are made in sets which are shaped in the form of globes, and a number of independent sets are required for the treatment of the different constituent gases. A sample pipette of the Hempel type is shown in Fig. 51.

The Nassau CO_2 Machine. Fig. 52 shows a CO_2 machine designed by F. F. Uehling. The jacket *E* surrounds the burette *A* and contains a solution of acidulated methyl orange. It

communicates with A at the bottom. By blowing into the top of E through the mouthpiece W, and tube G, the liquid will be forced into the burette A. When this is full, the three-way cock H is closed to A, to prevent the liquid returning to E. By means of pump P, gas will be drawn from the boiler or flue into the tube D, through the inlet I. When the gas reaches D, H is opened so as to connect the source of the gas with the absorption chamber B through a capillary tube C. B is the short leg of a U-tube and is filled with a caustic solution and fine iron wire to provide ample surface for quick absorption. When B is connected with the source of gas through H, the absorbent will rise in C to a certain level, depending upon the tension of the gas in D. The movable index X is then shifted to coincide with this level. Cock H is then turned so as to connect D with A, and by means of the mouthpiece W, the gas is drawn from D into A until the level of the liquid in A coincides with the zero line of the scale. The burette then contains 100 volumes of the gas. Now by turning the cock H so as to connect A with B, opening the pinchcock K and blowing through W, the gas will be forced into B, where in less than thirty seconds the CO_2 in the gas will be entirely absorbed. The remaining gas is then drawn back into A until the level of the solution in B again reaches the index X. The pinchcock K is then closed and the level of the liquid in A will indicate the per cent of CO_2 absorbed.

CO_2 Recorders. Machines which will continuously record the percentage of CO_2 in flue gases have come into use in the past few years and have proved of great value in promoting efficiency in the operation of steam boilers. They are known as carbon dioxide recorders.

The Uehling Recorder is shown diagrammatically in Figs. 53 and 54. Referring to Fig. 53, the gas to be analyzed is drawn through two apertures, A and B, by a constant suction produced by an aspirator. If the apertures are kept at the same temperature, the suction or partial vacuum in the chamber between the two apertures will remain constant so long as the gas passes through both apertures; if, however, part of the gas be taken away or absorbed in the space between the two apertures, the vacuum will increase in proportion to the amount of gas absorbed. It is evident that if a manometer or light vacuum gage be con-

nected with this chamber, the amount of gas absorbed will be indicated by the vacuum reading.

Fig. 54 represents the more important parts of the complete instrument, which consists primarily of a filter, absorption chamber, two apertures (*A* and *B*) and a small steam aspirator. Gas is drawn from the furnace by means of the aspirator through a preliminary filter at the boiler. It is then drawn through other filters on the instrument, which insure that the gas flowing through the apparatus is clean. The clean gas passes through aperture *A*,

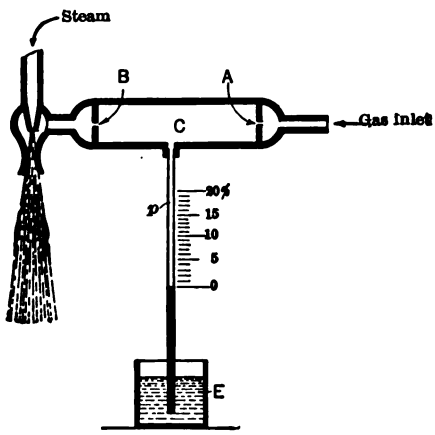

FIG. 53.—Principle of the Uehling Pyrometer and CO_2 apparatus.

thence through the absorption chamber and aperture *B*, to the aspirator.

A dilute solution of caustic soda flows into the absorption chamber by gravity from a tank, through a regulated sight-feed. The CO_2 is completely absorbed by the caustic solution as the gas flows through the absorption chamber and while it is between apertures *A* and *B* (in recent modifications of the instrument the solution is replaced by a solid absorbent). This reduces the volume and causes a change in the partial vacuum of the gas between the two apertures. This vacuum varies in exact accordance with the percentage of CO_2 contained in the gas, and is indicated by a water column at the instrument, which is calibrated so as to indicate directly percentages of CO_2. This partial vacuum or per-

centage of CO_2 is also communicated to an indicative gage in front of the boiler and to a recording gage which may be located at a considerable distance from the machine.

The "Sarco" Recorder, shown in Fig. 55 is an automatic, instrument which makes and records about 30 CO_2 analyses per hour. It requires no attention other than the changing of the recording chart every twenty-four hours and the renewal of

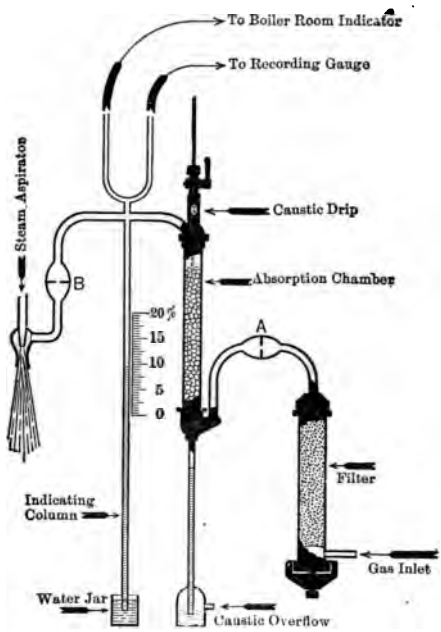

FIG. 54.—Diagram of the Uehling CO_2 Recorder.

the potash solution at intervals of about three weeks. Gas is aspirated by means of a fine stream of water, at a head of about 2 ft., which enters the instrument at 8 through the glass nozzle 9. The water flows through tube 74 to the power vessel 82 where it compresses the air above the water level. This pressure is transmitted through tube 78 to the surface of the liquid in vessel 87 and sends it upwards through tubes 91 and 93 into vessels 68, 67, 77 and 66, and into tubes 49, 51 and 52. The liquid rises until it reaches the zero mark 71 on the narrow neck of 67. At the same

moment the power water which has also risen in siphon 72, will have reached the top of this siphon, which then commences to

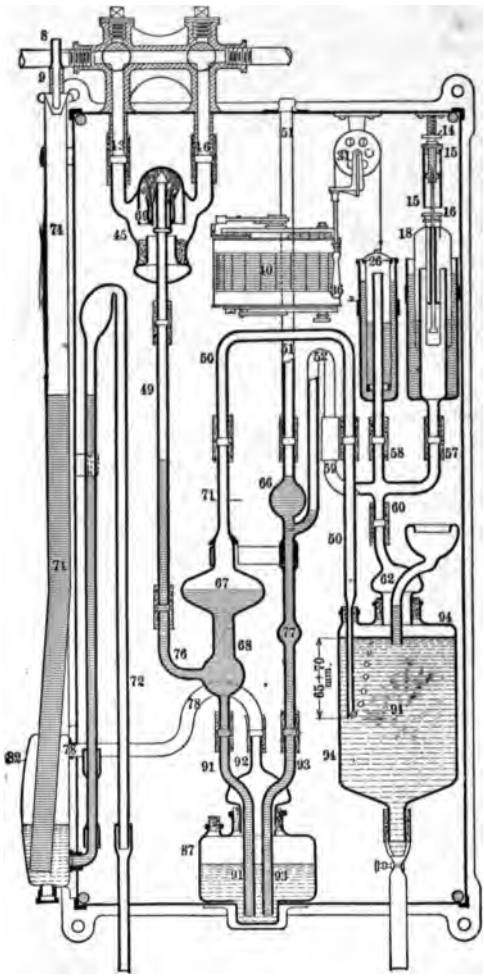

FIG. 55.—Sarco CO_2 Recorder.

operate, and empties the power vessels 74 and 82, releasing the pressure on 87 and returning the liquids from their respective tubes into 87.

Assuming that tube 49 is connected to a supply of flue gas, a sample will be drawn in from the continuous stream that passes through 43, 45 and 46, as the liquid recedes in 49, by the partial vacuum that is created by the falling of the liquid. As soon as the liquid has dropped below point 76 the gas rushes into vessel 67. When the flow in the siphon stops, vessel 82 again begins to fill and the liquids in tubes 91 and 93 rise afresh. The gas in 67 and 68 is forced into tube 50 and caused to pass through a solution of caustic potash (specific gravity 1.27) in vessel 94 which absorbs any CO_2 that may be present in the gas. The remaining portion of the sample collects in 62 and passes through 60 into tubes 57 and 58. It cannot pass out at 59, as this outlet is sealed by the liquid in 52.

The gas then passes under the two floats 18 and 26. The former is larger and lighter and therefore will be raised first. The stroke of this float is adjusted by the thumbscrews 14 and 15 until just 20 per cent of the whole sample remains to raise float 26, when nothing is absorbed by the potash solution as would be the case if air passed through the recorder. A pen 36 is caused to travel down on the chart 40 when float 26 rises. If no CO_2 were contained in the gas, nothing would be absorbed by the potash solution and the pan would travel the whole depth of the chart to the zero line at the bottom. Any CO_2 in the sample would be absorbed by the potash, a correspondingly less quantity would reach the float 26 and the pen would cover a proportionately less distance on the chart. The actual percentage of CO_2 would be shown by the line on which the pen stops. On the return stroke of the liquid, the gas is pushed out from under floats 18 and 26, through tubes 57 and 58 into tubes 59 and 62. Thence it passes into 66 as soon as the liquid has fallen below the outlet of tube 52 and escapes through tube 51.

TEMPERATURE OF THE WASTE GASES

As in analyzing coal, cinders, and gases we must have average samples, so in treating of waste gases we need average temperatures. Taking the temperature occasionally with the thermometer has grave possibilities of error. The temperature varies greatly from time to time, and even if the readings are taken

frequently their average may be far from correct average of the gas temperature. The real average temperature of the gas current can be obtained by means of a heat reservoir introduced into the flue.

An apparatus for this purpose was devised by Scheurer-Kestner, the type which has been repeatedly copied and modified. It consists of an iron tube, *bb* (Fig. 56), placed in the flue so that the upper end, covered with an insulating material, is let into the wall to about one half its thickness, the remainder hanging free in the flue. This tube is filled with paraffin, and in this is inserted the thermometer. The large mass of the paraffin is acted on by the mean temperature, but is uninfluenced by any slight momentary changes which may occur. A self-registering thermometer is very advantageous, but readings at intervals of half an hour are sufficient ordinarily. Of course the opening around the tube should be packed so as to prevent all possible ingress of cold external air.

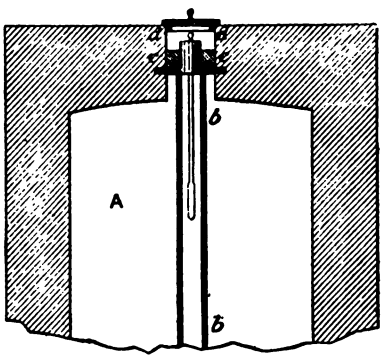

FIG. 56.—Flue Thermometer.

Occasionally mercury is used instead of paraffin. This renders the average of the heat more exactly, perhaps, but has the disadvantage of being much heavier and much more expensive. There are also many difficulties in handling it which do not obtain with paraffin. The paraffin should be well refined, and have a high melting-point.

The Uehling Pyrometer. The principle of the CO_2 apparatus described on page 201 is also applied in the Uehling pyrometer. The aperture *A* (Fig. 54) is located in a nickel tube which is exposed to the heat to be measured, while the aperture *B* is kept at a lower temperature, usually by inclosing it in a chamber surrounded by exhaust steam at atmospheric pressure. The suction at the aspirator being constant, the partial vacuum at *C* will depend on the difference of temperatures at *A* and *B*, and this vacuum is indicated on a water gage and also on a recording

gage as in the CO_2 apparatus, the graduations being made to record temperatures directly.

A pyrometer and CO_2 apparatus are also combined in one machine.

VOLUME OF WASTE GASES

The *fan-wheel anemometer* is an instrument to measure the force or rapidity of a current of gas. It consists of a fan-wheel rotated by the moving gas, and which transmits this motion to an index showing the number of revolutions. Burnat used this apparatus to measure the quantity of air passing to the grate under steam boilers.

Fletcher's Anemometer. Fletcher's anemometer (Fig. 57)

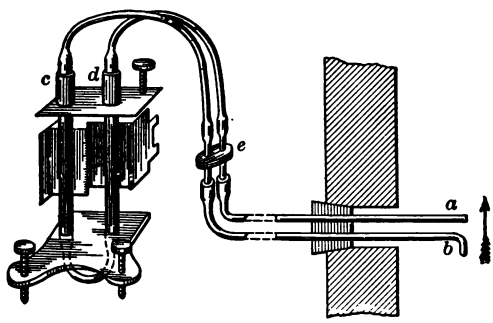

FIG. 57.—Fletcher's Anemometer.

is used in England to ascertain the speed of flow in chimneys and flues. In its simplified form it is quite serviceable. It is based on the movement of a column of ether in a U-tube.

The ends of the glass tubes *a*, *b* are placed in the flue projecting into it a little less than one-sixth of its diameter. The straight end *a* should be parallel to the direction of the current, and the end *b* at right angles to it. Hunter proposed bending both ends in opposite directions, to obviate the error caused if the tubes were not so placed. These tubes communicate with the ether tube *cd*. The draft across the tubes causes the ether to rise in *a* by aspiration and to fall in *b* by pressure. The difference of level is read, the tubes are turned through 180 degrees so as to reverse their positions, and the difference of level read again.

The sum of the two differences is called the anemometer reading, and by means of tables the velocity of the current is ascertained.

The same trouble is common to all anemometer methods. The flue feeding the fire receives only the air passing in under the grate. Whatever passes in by the doors or through cracks escapes accounting. On account of this it is certain that the calculations based on anemometer readings are lower than the actual air supply.

Segur's Differential Gage. Segur's differential gage (Fig. 58) consists of a U-tube of ½-in. glass, surmounted by two chambers 2½ in. diameter. Two nonmiscible liquids of different colors, usually alcohol and paraffin oil, are placed in the two arms, one occupying the portion *AB*, the other the portion *BCD*. The movement of the line of demarcation is proportional to the difference in area of the chambers and the tube adjoining. A movement of 2 in. in the column represents ¼-in. difference of pressure or draft.

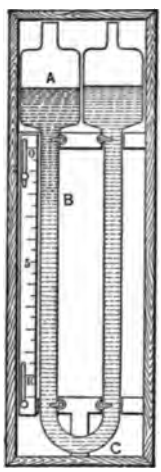

FIG. 58.—Segur Gage.

Hirn's Method. The apparatus used by Burnat as a check on his own calculations was devised by Hirn, and is based on the formula for the rate of flow of compressed gases from a reservoir, friction being neglected. The coefficient of reduction used is 0.9, the one given by Dubuisson in his treatise on hydraulics.

The main difficulty consists in measuring the difference of pressure of the atmosphere in the ash pit and that outside, for the depression in the flues in some cases does not exceed a few millimeters of water. Hirn's apparatus removes this difficulty.

Burnat describes it as follows:

When making a test the doors of the ash pit are removed and replaced by a piece of sheet iron, *A* (Fig. 59), which completely shuts out all access of air except through the opening in the middle, to which is fitted the pipe *CD*, 13.8 in. diameter and 59 in. long. A tube leads from the front to the apparatus *E*, devised by Hirn, placed on a table or against the boiler wall. This apparatus consists of a small gas-holder whose upper surface

is just one decimeter (3.9 in.) on a side. Inside this and above the water level the tube B opens. The bell dips into a vessel of water and is suspended from a balance arm.

The balance being in equilibrium when the atmospheric pressure acts on both sides of the bell, if the interior is connected with the ash pit the weight needed to restore equilibrium will give a measure of the difference in pressure. The

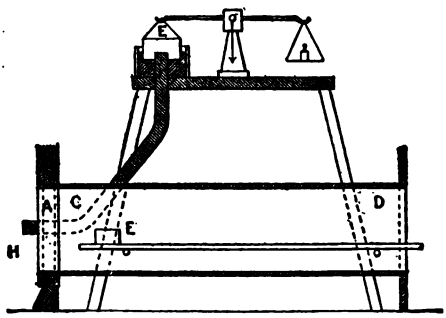

FIG. 59.—Hirn's Apparatus.

weight of half a gram (7.7 grains) represents one-twentieth millimeter (0.002 in.) of water.

The formula adopted by Hirn is

$$V = S \times 0.9 \sqrt{2g \frac{h \times 0.76(1+0.0037t)}{0.0013B}},$$

in which

V = volume of air introduced under the grate in cubic meters;

S = section in square meters of pipe-opening leading air to the ash pit;

0.9 = coefficient of reduction;

h = difference of pressure expressed in height of water;

B = barometric pressure in the room;

t = temperature of the room;

g = acceleration of gravity = 9.8088 meters.

Kent's Gage. Fig. 60 represents a sensitive and accurate draft-gage constructed by William Kent. A light cylindrical

tin can *A*, 5 in. diameter and 6 in. high, is inverted and suspended inside of a can *B*, 6 in. diameter, 6 in. high, by means of a long helical spring. A $\frac{1}{4}$-in. tube is placed inside of the larger can, with one end just below the level of the upper edge, while the other end passes through a hole cut in the side of the can, close to the bottom. The can is filled with water to within about half

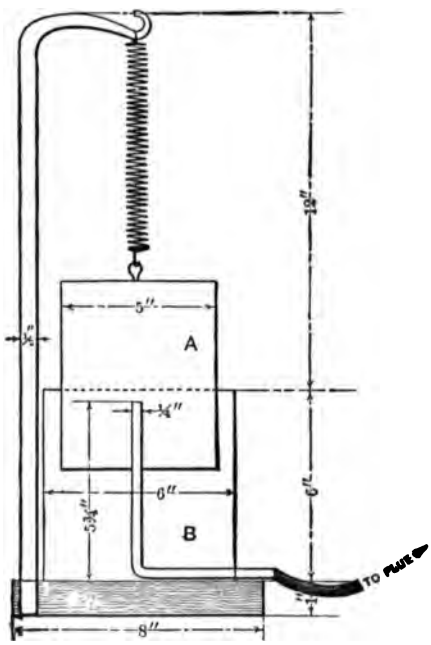

FIG. 60.—Kent's Draft Gage.

an inch of the top, and the inner can is suspended by the spring so that its lower edge dips into the water.

The small tube being open at both ends, the air inclosed in the can *A* is at atmospheric pressure, and the spring is extended by the weight of the can. The end of the tube which projects from the bottom of the can being now connected by means of a rubber tube with a tube leading into the flue, or other chamber, whose draft or suction is to be measured, air is drawn out of the can *A* until the pressure of the remaining air is the same as that of the flue. The external atmosphere pressing

on the top of the can A causes it to sink deeper in the water, extending the spring until its increased tension just balances the difference of the opposing vertical pressures of the air inside and outside of the can. The product of this difference in pressure, expressed as a decimal fraction of a pound per square inch, multiplied by the internal area of the can in square inches, equals the tension of the spring (above that due to the weight of the can) in pounds or fraction of a pound. The extension of a helical spring being proportional to the force applied, the distance traveled downward by the can A measures the force of suction, that is, the draft. The movement of the can may conveniently be measured by having a celluloid scale graduated to fiftieths of an inch fastened to the side of the can A, the can carrying an index.

To reduce the readings of the scale to their equivalents in inches of water column, as read on the ordinary U-tube gage, we have the following formulæ:

Let P = force in pounds required to stretch the spring 1 in.

E = elongation of the spring in inches;

A = area of the inner can in square inches;

d = difference in pressure or force of the draft in pounds per square inch;

D = difference in pressure in inches of water = $27.71d$.

$$EP = Ad = \frac{AD}{27.71} = 0.0361AD;$$

$$D = \frac{27.71EP}{A};$$

$$E = \frac{0.0361AD}{P}.$$

The last equation shows that for a constant force of draft the elongation of the spring or the movement of the can may be increased by increasing the area of the can or by decreasing the strength of the spring.

Applying the above formulæ, the movement of the can corresponding to a draft of 1 in. of water column, the can A having a diameter of 5 in. = 19.63 in. area, and the spring of such a

strength that 0.1 lb. elongates it 1 in. Here $P=0.1$; $A=19.63$; $D=1$.

$$E=\frac{0.0361\times 19.63}{0.1}=7.09 \text{ in.}$$

That is, the instrument multiplies the readings of the U-tube 7.09 times. The precision of the instrument is, however, far greater than this figure would indicate; for in the U-tube it is exceedingly difficult to read with precision the difference in height of the two menisci, while with this apparatus readings in the scale may easily be made to $1/50$ inch, which with the multiplication of 7, is equivalent to $1/350$ of an inch of water column. The instrument may also be calibrated by directly comparing its readings with those of an ordinary U-tube gage.

The Ellison Differential Draft Gage (Fig. 61) consists of an

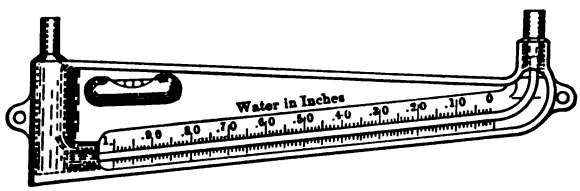

FIG. 61.—Ellison Draft Gage.

inclined tube of small caliber attached to a vertical tube of large diameter. These are mounted on an aluminum case, with a graduated scale along the inclined tube. The tubes are filled with a light non-drying mineral oil (sp.gr. 0.834), and the graduations are so made that the figures correspond to hundredths of an inch of water-level. In the combination gage the lower end of the inclined tube joins a U-tube, so that pressures up to 5 in. of water may be measured, the graduations in the U-tube being tenths of an inch.

The Blonck Differential Draft Gage registers a difference in pressure or draft between the damper and the furnace. The amount of gas flowing from the furnace to the flue damper is proportional to the velocity. The velocity depends on the difference of pressure at the entrance and the end of the passage. If the gases were of uniform temperature and pressure,

the quantity flowing would be proportional to the square root of the pressure difference, but this law is modified by variations in the temperature and density, but within the ordinary range of conditions of boiler practice it is approxiamtely true. If the furnace conditions are constant, so that the gas always contains the same percentage of CO_2 and of O, then the amount of fuel burned

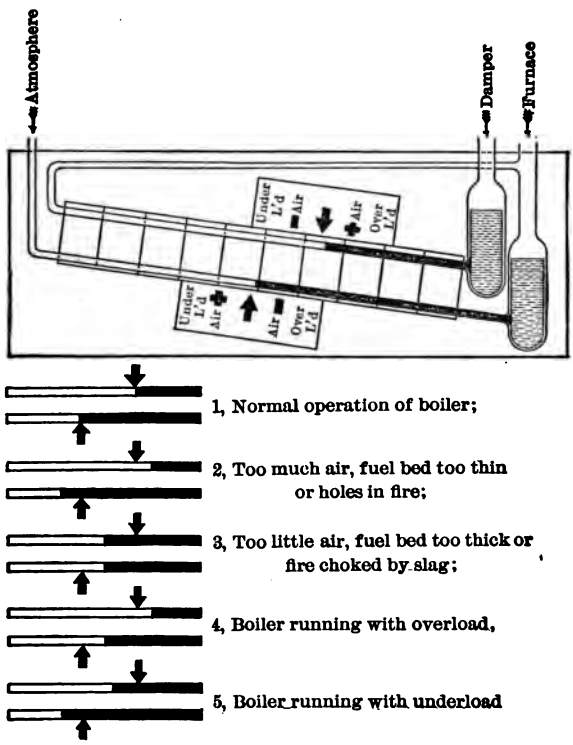

FIG. 62.—Diagram of Blonck Efficiency Meter and Principal Indications of the Instrument.

in a given time is proportional to the gas volume, and the boiler capacity is also approximately proportional to it within moderate ranges of excess driving. Having once established by experiment the difference of draft pressure that gives a normal rate of driving of a given boiler, a differential pressure gage will indicate whether the boiler is developing more or less than its rated

capacity. An increase in the draft between the furnace and the damper may, however, be caused not only by excessive driving, but also abnormal furnace conditions, such as too thin fires or holes in the fires. These conditions may be shown by a second gage which shows the difference in pressure between the ash pit and the furnace. If the normal difference for a given rate of driving be established, a decrease in that difference means decreased resistance of the fuel bed, which may be due to thin fires or to holes. An increased difference means increased resistance caused by too thick fires or fires choked by clinker coal or by caking, or grates choked by ash or clinker. The Blonck efficiency meter (Fig. 62) takes the place of the two gages. It consists essentially of two sensitive draft gages. The lower one is filled with red oil and gives a relative indication of the pressure with which the air passes into the furnace or the resistance of the fuel bed. The upper gage is filled with blue oil, and gives a relative measure of the amount of combustion gases passing the boiler proper. The meter is provided with two sliding scales which are to be adjusted to the best and most efficient operating condition of the particular boiler. The deductions to be read from the various positions of the oils in the instrument are shown in the diagram below the illustration. In order to instruct the fireman about the correction of wasteful conditions in the fire, the sliding scales are provided with the abbreviations: normal position (arrow); excess air (+ air), and lack of air (− air).

The Uehling Triple Draft Gage (Fig. 63) is arranged to show the difference in pressure between the ash pit, the combustion chamber and the damper at will. Attached in front of the scale in an inclined position is a large glass tube *LL* containing a small tube *H* which protrudes from the tube *LL* at its upper end. *H* and *L* respectively are in communication with the five-way valve *C* through the connections *D* and *K*. The valve *C* is further connected through suitable pipes *A* with the ash pit, *I* with the furnace and *G* with gas exit between the boiler and the damper. The valve *C* is operated by a movable index *J* which revolves in front of a dial upon which the letters *O*, *T*, *F*, *B* are shown. When the index points to *O*, *H* and *L* are in communication and the gage shows zero. When it is moved to *T*, *H* and *L* are in communication respectively with *A* and *G* and the gage shows the total

draft between the ash pit and damper. When the index is moved to *F*, *H* and *L* respectively communicate with *A* and *I* and the gage shows furnace draft, i.e., the drop of pressure or resistance through the fire. If the index is moved to *B*, *H* and *L*

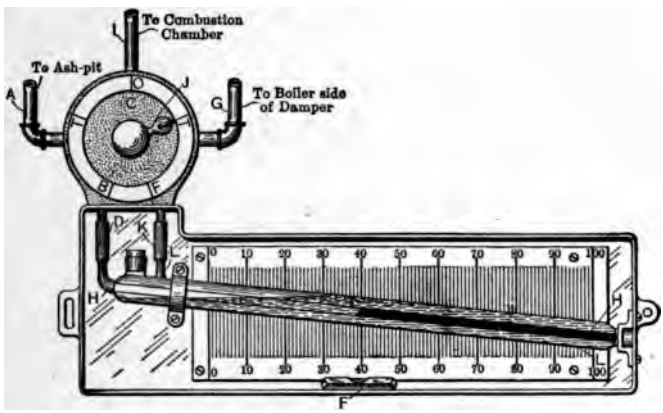

FIG. 63.—The Uehling Triple Draft Gage.

respectively communicate with *I* and *G* and the gage shows the boiler draft, i.e., the drop of pressure between the furnace and the damper.

APPENDIX

BOILER TESTS

Evaporation tests of steam boilers should be conducted in accordance with the Power Code of the American Society of Mechanical Engineers. Those portions of the code relating specifically to boiler tests are abstracted below.

Instructions Regarding Tests in General

(Code of 1915)

OBJECT

Ascertain the specific object of the test, and keep this in view not not only in the work of preparation, but also during the progress of the test.

If questions of fulfillment of contract are involved, there should be a clear understanding between all the parties, preferably in writing, as to the operating conditions which should obtain during the trial, the methods of testing to be followed, corrections to be made in case the conditions actually existing during the test differ from those specified, and all other matters about which dispute may arise, unless these are already expressed in the contract itself.

PREPARATIONS

Dimensions. Measure the dimensions of the principal parts of the apparatus to be tested, so far as they bear on the objects in view, or determine them from working drawings. Notice the general features of the apparatus, both exterior and interior, and make sketches, if needed, to show unusual points of design.

The areas of the heating surfaces of boilers and superheaters to be found are those of surfaces in contact with the fire or hot gases. The submerged surfaces in boilers at the mean water level should be considered as water-heating surfaces, and other surfaces which are exposed to the gases as superheating surfaces.

Examination of Plant. Make a thorough examination of the physical condition of all parts of the plant or apparatus which concern the object in view, and record the conditions found.

In boilers examine for leakage of tubes and riveted or other metal joints. Note the condition of brick furnaces, grates and baffles. Examine brick walls and cleaning doors for air leaks, either by shutting the damper and observing the escaping smoke or by candle-flame test. Determine the condition of heating surfaces with reference to exterior deposits of soot and interior deposits of mud or scale.

If the object of the test is to determine the highest efficiency or capacity obtainable, any physical defects, or defects of operation, tending to make the result unfavorable should first be remedied; all fouled parts being cleaned, and the whole put in first-class condition. If, on the other hand, the object is to ascertain the performance under existing conditions, no such preparation is either required or desired.

Precautions against Leakage. In steam tests make sure that there is no leakage through blowoffs, drips, etc., or any steam or water connections, which would in any way affect the results. All such connections should be blanked off, or satisfactory assurance should be obtained that there is leakage neither out nor in.

Apparatus and Instruments. See that the apparatus and instruments are substantially reliable, and arrange them in such a way as to obtain correct data.

Weighing Scales. For determining the weight of coal, oil, water, etc., ordinary platform scales serve every purpose. Too much dependence, however, should not be placed upon their reliability without first calibrating them by the use of standard weights, and carefully examining the knife-edges, bearing plates, and ring suspensions, to see that they are all in good order.

For testing locomotives and some classes of marine boilers, where room is lacking, sacks or bags are sometimes required to facilitate the handling of coal, the weighing being done before loading on the tender or delivery to the fire room.

Water Weighing and Measuring Apparatus. Wherever practicable the feedwater should be weighed, especially for guarantee tests. The most satisfactory and reliable apparatus for this purpose consists of one or more tanks each placed on platform scales, these being elevated a sufficient distance above the floor to empty into a receiving tank placed below, the latter being connected to the feed pump. Measuring tanks calibrated by weighing may also be used.

In tests of complete steam power plants, where it is required to measure the feedwater without unnecessary change in the working conditions, a water meter may be employed. Meter measurement may also be required in many other cases, such as locomotive and marine service. The accuracy of meters should be determined by calibration in place under the conditions of use.

If a large quantity of water is to measured, an automatic water-weigher, a rotary, disk, or Venturi meter, a weir, or some form of orifice measurement may be employed. The measuring apparatus should be calibrated under the conditions of use, unless its design is such that standard formulæ and constants may be applied for determining the discharge. If recording mechanism is employed in connection with orifice or weir measuring apparatus, make sure that its record is reliable.

Steam Measuring Apparatus. Various forms of steam meters may be employed for measuring steam, provided such meters are properly calibrated under conditions of use, and the pulsations of pressure, if any, are not serious.

Pressure Gages. For determining pressure the gages belonging to the plant may be used, provided they are compared with a standardized gage of the spring or mercury type and verified, due allowance being made for the head of water, if any, standing in the connecting pipe. Such comparisons should be made with both gages at their respective normal temperatures. In the use of spring gages for steam the gages should be protected by proper syphons or water seals and no leakage should be allowed at the gage-cock. The gages should also be located so that they will not be unduly heated.

Thermometers. Thermometers should be of the kind having graduations marked on the glass stem. Those used for temperatures above the boiling-point of mercury (or say above 500 deg. Fahr.) should have nitrogen in the top of the bore. They should also have a small safety bulb at the top. Thermometers constructed in this way can be used satisfactorily up to 1000 deg. Fahr.

Thermometers which are used for important data should be calibrated before and after a test, by reference to standard thermometers.

Pyrometers. Metallic pyrometers used for determining high temperatures must be handled cautiously owing to the difficulty of exposing the whole of the stem to the current of gas, the temperature of which is to be determined. Electric pyrometers either of the thermo-couple or resistance type are satisfactory for this work within their practical range, which is 1800 deg. Fahr. for iron-nickel couples and 3000 deg. Fahr. for platinum-iridium couples or platinum resistance pyrometers. Instruments of this kind can readily be calibrated by comparing them at low ranges of temperature with a standardized mercurial thermometer, both being placed for example in a current of hot air the temperature of which is under control. For extremely high temperatures such as that of a boiler furnace, the optical, pneumatic, and radiation pyrometers may be used. The calibration of high-temperature instruments can best be undertaken in a laboratory especially fitted for the purpose.

Draft Gages. When the ordinary U-tube is kept clean and the two legs are close together with the scale extending at least to the center of each leg, it gives satisfactory indications. For measuring small amounts of draft some form of multiplying gage may be employed, such as a U-tube in which one leg is inclined from the horizontal, the multiplication varying inversely as the sine of the angle of inclination, the tube being filled with a light mineral oil. These can be calibrated by comparison with the simple U-tube gage when indicating a high-draft, say 1 in. or more. It is perferable to use kerosene instead of water in the U-tube, and make allowance for the difference of specific gravity. Draft readings should be expressed in inches of water-column.

Steam Calorimeters. The most satisfactory instruments for determining the amount of moisture in steam are calorimeters that operate upon the throttling principle, or that combine the throttling and separating principles; the orifice used being of such size as to throttle to atmospheric pressure, and the instrument being provided with two thermometers, one showing the temperature above the orifice and the other that below it. Instruments working on the separating principle alone may also be employed; also certain forms of electric calorimeters.

Fuel Calorimeters. To determine the total heat of combustion of a sample of coal or other fuel, the best form of calorimeter is one in which the fuel is burned in an atmosphere of oxygen gas. The Mahler type of calorimeter is recognized as the most complete and accurate apparatus of this kind. The total heat of combustion of gas should be found by burning the gas in the Junker calorimeter.

Smoke Determination. No wholly satisfactory methods for smoke determinations have yet come into use, nor have any reliable methods been established for definitely fixing even the relative density of the smoke issuing from chimneys at different times. One method commonly employed which answers the purpose fairly well, is that of making frequent visual observations of the chimney at intervals of one minute or less for a period of one hour and recording the observed characteristics according to the degree of blackness and density, and giving to the various degrees of smoke an arbitrary percentage value rated in some such manner as that expressed in the following table:

SMOKE PERCENTAGES

Dense black	100
Medium black	80
Dense gray	60
Medium gray	40
Light gray	20
Very light	5
Trace	1
Clear chimney	0

The color and density of smoke depend somewhat on the character of the sky or other background, and on the air and weather conditions obtaining when the observation is made, and these should be given due consideration in making comparisons. Observations of this kind are also subject to personal errors and errors of judgment. Nevertheless, these methods are useful, especially when the results are plotted, according to the percentage scale determined on, so that a graphic representation of the changes can be shown.

SAMPLING AND DRYING COAL

Select a representative shovelful from each barrow-load as it is drawn from the coal pile or other source of supply, and store the samples in a cool place in a covered metal receptacle. When all the coal has thus been sampled, break up the lumps, thoroughly mix the whole quantity, and finally reduce it by the process of repeated quartering and crushing

to a sample weighing about 5 lb., the largest pieces being about the size of a pea. From this sample two 1-qt. air-tight glass fruit jars, or other air-tight vessels, are to be promptly filled and preserved for subsequent determinations of moisture, calorific value, and chemical composition.

When the sample lot of coal has been reduced by quartering to say 100 lb., a portion weighing say 15 to 20 lb. should be withdrawn for the purpose of immediate moisture determination. This is placed in a shallow iron pan and dried on the hot boiler flue for at least 12 hours, being weighed before and after drying on scales reading to quarter ounces.

The moisture thus determined is approximately reliable for anthracite and semi-bituminous coals, but not for coals containing much inherent moisture. For such coals, and for all reliable determinations the method to be pursued is as follows:

Take one of the samples contained in the glass jars, and subject it to a thorough air drying, by spreading it in a thin layer and exposing it for several hours to the atmosphere of a warm room, weighing it before and after, thereby determining the quantity of surface moisture it contains. Then crush the whole of it by running it through an ordinary coffee mill or other suitable crusher adjusted so as to produce somewhat coarse grains (less than $1/16$ in.), thoroughly mix the crushed sample, select from it a portion of from 10 to 50 grams (say $1/2$ to. of 2 oz.), weigh it in a balance which will easily show a variation as small as 1 part in 1000, and dry it for one hour in an air or sand bath at a temperature between 240 and 280 deg. Fahr. Weigh it and record the loss, then heat and weigh again until the minimum weight has been reached. The difference between the original and the minimum weight is the moisture in the air-dried coal. The sum of the moisture thus found and that of the surface moisture is the total moisture.

If a large drying oven is available the moisture may be determined by heating one of the glass jars full of coal, the cover being removed, at a temperature between 240 and 280 deg. Fahr. until it reaches the minimum weight.

With certain lignite lower temperatures for drying may be advisable.

SAMPLING ASHES AND REFUSE

The general method above described may also be followed for obtaining a sample of the ashes and refuse, and for determining the amount of moisture, if any, in the sample.

SAMPLING STEAM

Construct a sampling pipe or nozzle made of ½-in. iron pipe and insert it in the steam main at a point where the entrained moisture is likely to be most thoroughly mixed. The inner end of the pipe, which should extend nearly across to the opposite side of the main, should be closed and the interior portion perforated with not less than twenty

⅛-in. holes equally distributed from end to end and preferably drilled in irregular or spiral rows, with the first hole not less than half an inch from the wall of the pipe. (See Fig. 64.)

The sampling pipe should not be placed near a point where water may pocket or where such water may affect the amount of moisture contained in the sample.

PROXIMATE ANALYSIS OF AIR-DRIED COAL

To determine volatile matter place about 1 gram of the air-dried powdered coal in the crucible and heat it in a drying oven to 220 deg. Fahr. for one hour (or longer if necessary to obtain the minimum weight), cool in a desiccator and weigh. Cover the crucible with a loose platinum plate. Heat seven minutes with a Bunsen burner giving a 6 to 8-in.

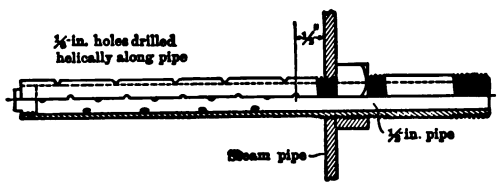

FIG. 64.—Pipe for Sampling Steam.

flame, the crucible being supported 3 in. above the top of the burner tube and protected from outside air currents by a cylindrical asbestos chimney 3 in. diameter. Cool in a desiccator, remove the cover and weigh. The loss in weight represents the volatile matter.

To ascertain the ash, heat the residue in the crucible by a blast lamp until it is completely burned, using a stream of oxygen if desired to hasten the process. The residue is the ash.

The difference between the residue left after the expulsion of the volatile matter and the ash is the fixed carbon.

SAMPLING FLUE GASES

The sample for flue gas analysis should be drawn from the region near the center of the main body of escaping gases, using a sampling pipe not larger than ¼-in. gas pipe. The point selected should be one where there is no chance for air-leakage into the flue which could affect the average quality. In a round or square flue having an area of not more than one-eighth of the grate surface, the sampling pipe may be introduced horizontally at a central line, or preferably a little higher than this line, and the pipe should contain perforations extending the whole

length of the part immersed, pointing toward the current of gas, the collective area of the perforations being less than the area of the pipe. The pipe should be frequently removed and cleaned.

It is advisible to take samples both from the flue and from the furnace, so as to determine the amount of air leakage through the setting and

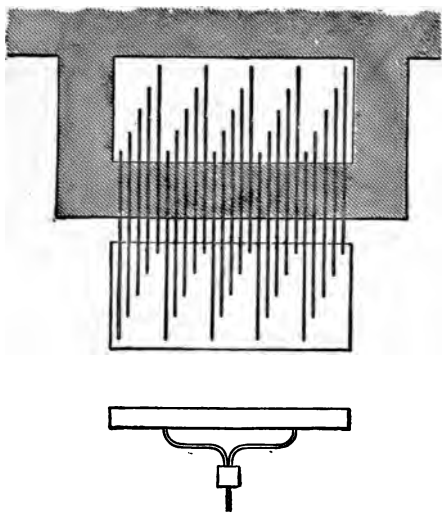

FIG. 65.—Method of Sampling Flue Gas.

the changes in the composition of the gas between the furnace and the flue.

It is best to draw a continuous sample, using a suitable aspirator, and provide a branch pipe from which to obtain the test-sample. The test sample can then be taken either momentarily or continuously, according to the requirements.

MISCELLANEOUS INSTRUCTIONS

The person in charge of a test should have the aid of a sufficient number of assistants, so that he may be free to give special attention to any part of the work whenever and wherever it may be required. He should make sure that the instruments and testing apparatus continually give reliable indications, and that the readings are correctly recorded. He should also keep in view, at all points, the operation of the plant or part of the plant under test and see that the operating conditions determined on are maintained and that nothing occurs, either by accident or design, to vitiate the data. This last precaution is especially needed in guarantee tests.

Before a test is undertaken, it is important that the boiler, engine, or other apparatus concerned shall have been in operation a sufficient length of time to attain working temperatures and proper operating conditions throughout, so that the results of the test may express the true working performance.

It would, for example, be manifestly inproper to start a test for determining the maximum efficiency of an externally fired boiler with a brick setting, until the boiler had been at work a sufficient number of days to dry out thoroughly and heat the brick work to its working temperature.

An exception should be noted where the object of the test is to obtain the working performance, including the effect of preliminary heating, in which case all the conditions should conform to those of regular service.

In preparation for a test to demonstrate maximum efficiency, it is desirable to run preliminary tests for the purpose of determining the most advantageous conditions.

OPERATING CONDITIONS

In all tests in which the object is to determine the performance under conditions of maximum efficiency, or where it is desired to ascertain the effect of predetermined conditions of operation, all such conditions which have an appreciable effect upon the efficiency should be maintained as nearly uniform during the trial as the limitations of practical work will permit. Where maximum efficiency is the object in view, there should be uniformity in such matters as steam pressure, times of firing, quantity of coal supplied at each firing, thickness of fire, and in other firing operations; also in the rate of supplying the feedwater, in the load, and in the operating conditions throughout. On the other hand, if the object of the test is to determine the performance under working conditions, no attempt at uniformity is either desired or required unless this uniformity corresponds to the regular practice, and when this is the object the usual working conditions should prevail throughout the trial.

RECORDS

A log of the data should be entered in note-books or on blank sheets suitably prepared in advance. This should be done in such manner that the test may be divided into hourly periods, or if necessary, periods of less duration, and the leading data obtained for any one or more periods as desired, thereby showing the degree of uniformity obtained.

The readings of instruments and apparatus concerned in the test other than those showing quantities of consumption (such as fuel,

water, and gas), should be taken at intervals not exceeding half an hour and entered in the log. When the indications fluctuate, the intervals should be reduced. In the case of smoke observations it is often necessary to take observations every minute, or still oftener.

Make a memorandum of every event connected with the progress of a test, however unnecessary at the time it may appear. A record should be made of the exact time of every such occurrence and the time of taking every weight and every observation. For the purpose of identification the signature of the observer and the date should be affixed to each log sheet or record.

In the simple matter of weighing coal by the barrow-load, or weighing water by the tank-full, which is required in many tests, a series of marks, or tallies, should never be trusted. The time each load is weighed or emptied should be recorded. The weighing of coal should not be delegated to unreliable assistants, and whenever practicable, one or more men should be assigned solely to this work. The same may be said with regard to the weighing of feedwater.

PLOTTING DATA AND RESULTS

If it is desired to show the uniformity of the data at a glance the whole log of the trial should be plotted on a chart, preferably while the test is in progress, using horizontal distances to represent times of observation, and vertical distances on suitable scales to represent various data as recorded.

REPORT

The report of a test should present all the leading facts bearing on the design, dimensions, condition, and operation of the apparatus tested, and should include a description of any other apparatus and auxiliaries concerned, together with such sketches as may be needed for a clear understanding of all points under consideration. If should state clearly the object and character of the test, the methods followed, the conditions maintained, and the conclusions reached, closing with a tabular summary of the principal data and results.

Rules for Conducting Evaporative Tests of Boilers

OBJECT AND PREPARATIONS

Determine the object of the test, take the dimensions, note the physical conditions, examine for leakage, install the testing appliances, etc., as pointed out in the general instructions and make preparations for the test accordingly.

FUEL

Determine the character of fuel to be used. For tests of maximum efficiency or capacity of the boiler to compare with other boilers, the coal should be of some kind which is commercially regarded as a standard for the locality where the test is made.

A coal selected for maximum efficiency and capacity tests should be the best of its class, and especially free from slagging and unusual clinker-forming impurities.

For guarantee and other tests with a specified coal containing not more than a certain amount of ash and moisture, the coal selected should not be higher in ash and in moisture than the stated amounts because any increase is liable to reduce the efficiency and capacity more than the equivalent proportion of such increase.

OPERATING CONDITIONS

Determine what the operating conditions and method of firing should be to conform to the object in view, and see that they prevail throughout the trial, as nearly as possible.

Where uniformity in the rate of evaporation is required, arrangement can usually be made to dispose of the steam so that this result can be attained. In a single boiler it may be accomplished by discharging steam through a waste pipe and regulating the amount by means of a valve. In a battery of boilers, in which only one is tested, the draft may be regulated on the remaining boilers to meet the varying demands for steam, leaving the test boiler to work under a steady rate of evaporation.

DURATION

The duration of tests to determine the efficiency of a hand-fired boiler, should be at least ten hours of continuous running, or such times as may be required to burn a total of 250 lb. of coal per square foot of grate.

In the case of a boiler using a mechanical stoker, the duration, where practicable, should be at least twenty-four hours. If the stoker is of a type that permits the quantity and condition of the fuel bed at beginning and end of the test to be accurately estimated, the duration may be reduced to ten hours, or such time as may be required to burn the total of 250 lb. per square foot.

In commercial tests where the service requires continuous operation night and day, with frequent shifts of firemen, the duration of the test, whether the boilers are hand-fired or stoker-fired, should be at least twenty-four hours.

STARTING AND STOPPING

The conditions regarding the temperature of the furnace and boiler, the quantity and quality of the live coal and ash on the grates, the water

level, and the steam pressure, should be as nearly as possible the same at the end as at the beginning of the test.

To secure the desired equality of conditions with hand-fired boilers, the following method should be employed:

The furnace being well heated by a preliminary run, burn the fire low, and thoroughly clean it, leaving enough live coal spread evenly over the grate (say 2 to 4 in.).* to serve as a foundation for the new fire. Note quickly the thickness of the coal bed as nearly as it can be estimated or measured; also the water level,† the steam pressure, and the time, and record the latter as the starting time. Fresh coal should then be fired from that weighed for the test, the ash pit thoroughly cleaned, and the regular work of the test proceeded with.

Before the end of the test the fire should again be burned low and cleaned in such a manner as to leave the same amount of live coal on the grate as at the start. When this condition is reached, observe quickly the water level,† the steam pressure, and the time, and record the latter as the stopping time. If the water level is lower than at the beginning, a correction should be made by computation, rather than by feeding additional water. Finally remove the ashes and refuse from the ash pit.

In a plant containing several boilers where it is not practicable to clean them simultaneously, the fires should be cleaned one after the other as rapidly as may be, and each one after cleaning charged with enough coal to maintain a thin fire in good working condition. After the last fire is cleaned and in working condition, burn all the fires low (say 4 to 6 in.), note quickly the thickness of each, also the water levels, steam pressure, and time, which last is taken as the starting time. Likewise when the time arrives for closing the test, the fires should be quickly cleaned one by one, and when this work is completed they should all be burned low the same as at the start and the various observations made as noted.

In the case of a large boiler having several furnace doors requiring the fire to be cleaned in sections one after the other, the above directions pertaining to starting and stopping in a plant of several boilers may be followed.

To obtain the desired equality of conditions of the fire when a mechanical stoker other than a chain grate is used, the procedure should be modified where practicable as follows:

Regulate the coal feed so as to burn the fire to the low condition required for cleaning. Shut off the coal-feeding mechanism and fill the hoppers level full. Clean the ash or dump plate, note quickly the depth and condition of the coal on the grate, the water level, the steam pressure, and the time, and record the latter as the starting time. Then start the coal-feeding mechanism, clean the ash pit, and proceed with the regular work of the test.

When the time arrives for the close of the test, shut off the coal-feeding mechanism, fill the hoppers and burn the fire to the same low point as at

* 1 to 2 in. for small anthracite coals.

† Do not blow the water-glass column for at least one hour before these readings are taken. An erroneous indication may otherwise be caused by a charge of temperature and density of the water within the column and connecting pipe.

the beginning. When this condition is reached, note the water level, the steam pressure, and the time, and record the latter as the stopping time. Finally clean the ash plate and haul the ashes.

In the case of chain grate stokers, the desired operating conditions should be maintained for half an hour before starting a test and for a like period before its close, the height of the stoker gate or throat plate and the speed of the grate being the same during both of these periods.

RECORDS

Half-hourly readings of the instruments are usually sufficient. If there are sudden and wide fluctuations, the readings in such cases should be taken every fifteen minutes, and in some instances oftener.

In hand-fired tests the coal should be weighed and delivered to the firemen in portions sufficient for one hour's run, thereby ascertaining the degree of uniformity of firing. An ample supply of coal should be maintained at all times, but the quantity on the floor at the end of each hour should be as small as practicable, so that the same may be readily estimated and deducted from the total weight. Likewise in stoker tests the weight of coal fed to the furnace each hour should be determined.

The records should be such as to ascertain also the consumption of feedwater each hour, and thereby determine the degree of uniformity of evaporation.

QUALITY OF STEAM

If the boiler does not produce superheated steam the percentage of moisture in the steam should be determined by the use of a throttling or separating calorimeter. If the boiler has superheating surface, the temperature of the steam should be determined by the use of a thermometer inserted in a thermometer well in the steam pipe.

SAMPLING AND DRYING COAL

During the progress of the test the coal should be regularly sampled for the purpose of analysis and determination of moisture.

ASHES AND REFUSE

The ashes and refuse withdrawn from the furnace and ash pit during the progress of the test and at its close should be weighed so far as possible in a dry state. If wet the amount of moisture should be ascertained and allowed for, a sample being taken and dried for this purpose. This sample may serve also for analysis for the determination of unburned carbon.

CALORIFIC TESTS AND ANALYSES OF COAL

The quality of the fuel should be determined by calorific tests and analyses of the coal sample above referred to.

ANALYSES OF FLUE GASES

For approximate determinations of the composition of the flue gases the Orsat apparatus, or some modification thereof, should be employed. If momentary samples are obtained the analyses should be made as frequently as possible, say every fifteen to thirty minutes, depending on the skill of the operator, noting at the time the sample is drawn the furnace and firing conditions. If the sample drawn is a continuous one, the intervals may be made longer.

SMOKE OBSERVATIONS

In tests of bituminous coals requiring a determination of the amount of smoke produced, observations should be made regularly throughout the trial at intervals of five minutes (or if necessary every minute), noting at the same time the furnace and firing conditions.

For observations covering a period of one or more single firings, the intervals should be quarter minutes.

CALCULATION OF RESULTS

(*a*) *Corrections for Quality of Steam.* When the percentage of moisture is less than 2 per cent it is sufficient merely to deduct the percentage from the weight of water fed, in which case the factor of correction for quality is

$$1-\frac{\text{Per cent moisture}}{100}.$$

When the percentage is greater than 2 per cent, or if extreme accuracy is required, the factor of correction is

$$1-\frac{PH-h_1}{H-h},$$

in which P is the proportion of moisture, H the total heat of 1 lb. of saturated steam, h_1 the heat in water at the temperature of saturated steam, and h the heat in water at the feed temperature.

When the steam is superheated the factor of correction for quality of steam is

$$\frac{H_s-h}{H-h},$$

in which H_s is the total heat of 1 lb. of superheated steam of the observed temperature and pressure.

Unless otherwise provided, a combined boiler and superheater should be treated as one unit, and the equivalent of the work done by the superheater should be included in the evaporative work of the boiler.

(*b*) *Correction for Steam or Power used for Aiding Combustion.* The quantity of complete steam or power, if any, used for producing draft, injecting fuel, operating stokers, combustion, should be determined and recorded in the T

and Results. There should also be recorded, by foot-note below the table, a statement showing whether or not a deduction has been made from the total evaporation for steam or power used, and if such deduction has been made, the method of computing it.

(*c*) *Equivalent Evaporation.* The equivalent evaporation from and at 212 deg. Fahr. is obtained by multiplying the weight of water evaporated, corrected for moisture in steam, by the " factor of evaporation." The latter equals

$$\frac{H-h}{970.4},$$

in which H and h are respectively the total heat of saturated steam and of the feedwater entering the boiler.

The " factor of evaporation " and the " factor of correction for quality of steam " may be combined into one expression in the case of superheated steam as follows:

$$\frac{H_s-h}{970.4}.$$

(*d*) *Efficiency.* The " efficiency of boiler, furnace and grate " is the relation between the heat absorbed per pound of coal as fired, and the calorific value of 1 lb. of coal as fired.

The " efficiency based on combustible " is the relation between the heat absorbed per pound of combustible burned and the calorific value of 1 lb. of combustible. This expression of efficiency furnishes an approximate means for comparing the results of different tests when the losses of unburned coal due to grates, cleanings, etc., are eliminated.

The " combustible burned " is determined by subtracting from the weight of coal supplied to the boiler, the moisture in the coal, the weight of ash and unburned coal withdrawn from the furnace and ash pit, and the weight of dust, soot, and refuse, if any, withdrawn from the tubes, flues, and combustion chambers, including ash carried away in the gases, if any, determined from the analyses of coal and ash.* The " combustible " used for determining the calorific value is the weight of coal less the moisture and ash found by analysis.

The " heat absorbed " per pound of coal or combustible is calculated by multiplying the equivalent evaporation from and at 212 deg. per pound of coal or combustible by 970.4.

(*e*) *Heat Balance.* A " heat balance," or approximate distribution of the calorific value of 1 lb. of dry coal among the several items of heat utilized and heat lost, should be obtained in cases where the flue gases have been analyzed and a complete analysis made of the coal.

The loss due to moisture in the coal is found by multiplying the total heat of 1 lb. of superheated steam at the temperature of the escaping gases, calculated from the temperature of the air in the boiler room, by the proportion of moisture, referred to dry coal.

The loss due to moisture formed by the burning of hydrogen is obtained by multiplying the total heat of 1 lb. of superheated steam at the temperature of the escaping gases, calculated from the temperature of the air in the boiler room, by the proportion of the hydrogen, determined from

* The gases of high rates of combustion the determination of the combustible analyses of the fuel which are blown to waste. are subject to considerable error on account of the loss of cinders, soot

the analysis of the coal, referred to dry coal, and multiplying the result by 9.

The loss due to heat carried away in the dry gases is found by multiplying the weight of gas per pound of dry coal by the elevation of temperature of the gases above the temperature of the boiler room, and by the specific heat of the gases (0.24). The weight of gas per pound of dry coal is obtained by finding the weight of dry gas per pound of carbon burned, using the formula

$$\frac{11CO_2+8O+7(CO+N)}{3(CO_2+CO)},$$

in which CO_2, CO, O, and N are expressed in percentages by volume, and multiplying this result by the proportion borne by the carbon burned to the whole amount of dry coal as determined from the results of the analysis of the coal, ash, and refuse.

The loss due to incomplete combustion of carbon is found by first obtaining the proportion borne by the carbon monoxide in the gases to the sum of the carbon monoxide and carbon dioxide, and then multiplying this proportion by the proportion of carbon in the coal minus the carbon lost in the ash and refuse, and finally multiplying the product by 10,150, which is the number of heat units generated by burning to carbon dioxide 1 lb. of carbon contained in carbon monoxide.

The loss due to combustible matter in the ash and refuse is found by multiplying the proportion that this combustible bears to the whole amount of dry coal by its calorific value per pound. For most purposes it is sufficient to assume the latter to be 14,600 B.T.U., the same as that of carbon.

The loss due to moisture in the air is determined by multiplying the weight of such moisture per pound of dry coal by the elevation of temperature of the flue gases above the temperature of the boiler room and by 0.47. The weight of moisture is found by multiplying the weight of air per pound of dry coal by the moisture in 1 lb. of air determined from readings of the wet and dry bulb thermometer.

(*f*) *Total Heat of Combustion of Coal, by Analysis.* The total heat of combustion many be computed from the results of the ultimate analysis of using the formula

$$14{,}600C+62{,}000\left(H-\frac{O}{8}\right)+4000S,$$

in which C, H, O, and S refer to the proportions of carbon, hydrogen, oxygen, and sulphur respectively.

(*g*) *Air for Combustion.* The quantity of air used may be calculated by the formulæ:

$$\text{Pounds of air per pound of carbon}=\frac{3.032N}{CO_2+CO},$$

in which N, CO_2 and CO are the percentages of dry gas obtained by analysis and

Pounds of air per pound of coal = pounds air per pound C × (per cent C in the coal, less per cent carbon in refuse, referred to coal).

The ratio of the air supply to that theoretically required for complete combustion is $\frac{N}{N-3.782(O-\frac{1}{2}CO)}$.

DATA AND RESULTS

The data and results should be reported in accordance with the form printed below, adding lines for data not provided for, or omitting those not required, as may conform to the object in view.

CHART

In trials having for an object the determination and exposition of the complete boiler performance, the entire log of readings and data should be plotted on a chart and represented graphically.

TESTS WITH OIL AND GAS FUELS

Tests of boilers using oil or gas for fuel should accord with the rules here given, excepting as they are varied to conform to the particular characteristics of the fuel. The proper length of tests with gas and oil fuels may be determined by a consideration of the probable errors and the degree of accuracy desired, the minimum duration for economy tests being five hours. With these fuels the " flying " method of starting and stopping is employed.

The table of data and results should contain items stating character of furnace and burner, quality and composition of oil or gas, temperature of oil, and data regarding the performance of the apparatus supplying the fuel.

DATA AND RESULTS OF EVAPORATIVE TEST *

1.	Test of..To determine..Test conducted by..boiler located at..	
2.	Number and kind of boilers	
3.	Kind of furnace	
4.	Grate surface (width.....length.....)	Sq.ft.
5.	Water heating surface	"
6.	Superheating surface	"
7.	Total heating surface	"
	d. Volume of combustion space between grate and heating surface	"
	e. Distance from center of grate to nearest heating surface	Ft.
	Date, Duration, etc	
8.	Date	
9.	Duration	Hr.
10.	Kind and size of coal	
	Average Pressures, Temperatures, etc.	
11.	Steam pressure by gage	Lb.
12.	Temperature of steam, if superheated	Deg.
13.	Temperature of feedwater entering boiler	"
14.	Temperature of escaping gases leaving boiler	"

* This table contains the principal items of the table in the Code of 1915 of the A.S.M.E. Committee on Power Tests.

15. Force of draft between damper and boiler	In.
c. Draft in furnace	"
d. Draft or blast in ash pit	"
16. State of weather	
a. Temperature of external air	Deg.
b. Temperature of air entering ash pit	"
c. Relative humidity of air entering ash pit	"

Quality of Steam

17. Percentage of moisture in steam or degrees of superheating	Per cent or deg.
18. Factor of correction for quality of steam	"

Total Quantities

19. Total weight of coal as fired *	Lb.
20. Percentage of moisture in coal as fired	Per cent
21. Total weight of dry coal fired	Lb.
22. Total ash, clinkers, and refuse (dry) †	"
23. Total combustible burned (Item 21 − Item 22)	"
24. Percentage of ash and refuse in dry coal	Per cent
25. Total weight of water fed to boiler ‡	Lb.
26. Total water evaporated, corrected for quality of steam (Item 25 × Item 18)	Lb.
27. Factor of evaporation based on temperature of water entering boiler.	
28. Total equivalent evaporation from and at 212 deg. (Item 26 × Item 27)	Lb.

Hourly Quantities and Rates

29. Dry coal per hour	Lb.
30. Dry coal per square foot of grate surface per hour	"
31. Water evaporated per hour, corrected for quality of steam	"
32. Equivalent evaporation per hour from and at 212 deg. §	"
33. Equivalent evaporation per hour from and at 212 deg. per square foot of water heating surface *	"

Capacity

34. Evaporation per hour from and at 212 deg. (same as Item 32)	Lb.
a. Boiler horse-power developed (Item 34 ÷ 34½)	Bl. H.P.
35. Rated capacity per hour, from and at 212 deg.	Lb.
a. Rated boiler horse-power	Bl. H.P.
36. Percentage of rated capacity developed	Per cent

Economy

37. Water fed per pound of coal as fired (Item 25 ÷ Item 19)	Lb.
38. Water evaporated per pound of dry coal (Item 26 ÷ Item 21)	"
39. Equivalent evaporation from and at 212 deg. per pound of coal as fired (Item 28 ÷ Item 19)	"

* The term " as fired " means actual conditions including moisture. Weight corrected for estimated difference in weight of coal on the grate at beginning and end.

† Corrected when practicable for dust, soot, etc.

‡ Corrected for inequality of water level and of steam pressure at beginning and end.

§ The symbol " U. E." meaning Units of Evaporation, may be substituted for the expression, Equivalent evaporation from and at 212°.

40. Equivalent evaporation from and at 212 deg. per pound of dry coal (Item 28 ÷ Item 21)..... Lb.
41. Equivalent evaporation from and at 212 deg. per pound of combustible (Item 28 ÷ Item 23)..... "

Efficiency

42. Calorific value of 1 lb. of dry coal by calorimeter *..... B.T.U.
    a. Calorific value of 1 lb. dry coal by analysis..... "
43. Calorific value of 1 lb. of combustible by calorimeter..... "
    a. Calorific value of 1 lb. combustible by analysis..... "
44. Efficiency of boiler, furnace and grate,

$$100 \times \frac{\text{Item } 40 \times 970.4}{\text{Item } 42}.$$

45. Efficiency based on combustible,

$$100 \times \frac{\text{Item } 41 \times 970.4}{\text{Item } 43}.$$

Cost of Evaporation

46. Cost of coal per ton of ....pounds delivered in boiler room.... Dollars
47. Cost of coal required for evaporation 1000 lb. of water under observed conditions..... "
48. Cost of coal required for evaporating 1000 lb. of water from and at 212 deg..... "

Smoke Data

49. Percentage of smoke as observed..... Per cent

Firing Data

50. Kind of firing, whether spreading, alternate, or coking.....
    c. Average interval between times of leveling or breaking up. Min.
51. Analysis of dry gases by volume:
    a. Carbon dioxide (CO_2)..... Per cent
    b. Oxygen (O)..... "
    c. Carbon monoxide (CO)..... "
    d. Hydrogen and hydrocarbons..... "
    e. Nitrogen, by difference (N)..... "

52. Proximate analysis of coal

	As Fired.	Dry Coal.	Combustible.
a. Moisture		———	———
b. Volatile matter			
c. Fixed carbon			
d. Ash			———
	100%	100%	100%

    e. Sulphur, separately determined.....

* If the calorific value is desired per lb. of coal "as fired," multiply by (100 − Item 20) ÷ 100.

53. Ultimate analysis of dry coal:

a. Carbon (C)	Per cent
b. Hydrogen (H)	"
c. Oxygen (O)	"
d. Nitrogen (N)	"
e. Sulphur (S)	"
f. Ash	"

54. Analysis of Ash and Refuse, etc.

	Dry Coal.	
	B.T.U.	Per Cent.
55. Heat balance, based on dry coal and combustible:		
a. Heat absorbed by the boiler (Item 40 or 41×970.4)		
b. Loss due to evaporation of moisture in coal		
c. Loss due to heat carried away by steam formed by the burning of hydrogen		
d. Loss due to heat carried away in the dry flue gases		
e. Loss due to carbon monoxide		
f. Loss due to combustible in ash and refuse		
g. Loss due to heating moisture in air		
h. Loss due to unconsumed hydrogen and hydrocarbons, to radiation, and unaccounted for		
i. Total calorific value of 1 lb. of dry coal. (Item 42)		100

If it is desired that the heat balance be based on coal "as fired," or on "combustible burned," the items in the first column are multiplied by the proportion (100 − Item 20) ÷ 100 for coal "as fired," or by 100 ÷ (100 − Item 55*f*, per cent) for "combustible."

Principal Data and Results of Boiler Test

1. Grate surface (width.....length.....)	Sq.ft.
2. Total heating surface	"
3. Date	
4. Duration	Hr.
5. Kind and size of coal	
6. Steam pressure by gage	Lb.
7. Temperature of feedwater entering boiler	Deg.
8. Percentage of moisture in steam or number of degrees of superheating	Per cent or deg.
9. Percentage of moisture in coal	Per cent
10. Dry coal per hour	Lb.
11. Dry coal per square foot of grate surface per hour	"
12. Equivalent evaporation per hour from and at 212 deg.	"
13. Equivalent evaporation per hour from and at 212 deg. per square foot of heating surface	"

14. Rated capacity per hour, from and at 212 deg..... Lb.
15. Percentage of rated capacity developed..... Per cent
16. Equivalent evaporation from and at 212 deg. per pound of dry coal..... Lb.
17. Equivalent evaporation from and at 212 deg. per pound of combustible..... "
18. Calorific value of 1 lb. of dry coal by calorimeter..... B.T.U.
19. Calorific value of 1 lb. of combustible by calorimeter..... "
20. Efficiency of boiler, furnace, and grate,

$$100 \times \frac{\text{Item } 16 \times 970.4}{\text{Item } 18} \quad \text{Per cent}$$

21. Efficiency based on combustible,

$$100 \times \frac{\text{Item } 17 \times 970.4}{\text{Item } 19} \quad \text{Per cent}$$

BITUMINOUS COAL SIZES*

Bituminous coals in the Eastern States may be graded and sized as follows:

(*A*) Run of mine coal; the unscreened coal taken from the mine.

(*B*) Lump coal; that which passes over a bar-screen with openings 1¼ in. wide.

(*C*) Nut coal, that which passes through a bar-screen with 1¼-in. openings and over one with ¾-in. openings.

(*D*) Slack coal; that which passes through a bar-screen with ¾-in. openings.

Bituminous coals in the Western States may be graded and sized as follows:

(*E*) Run of mine coal; the unscreened coal taken from the mine.

(*F*) Lump coal; divided into 6-in., 3-in. and 1¼-in. lump, according to the diameter of the circular openings over which the respective grades pass; also 6 by 3 lump and 3 by 1¼ lump, according as the coal passes through a circular opening having the diameter of the larger figure and over that of the smaller diameter.

(*G*) Nut coal; divided into 3-in. steam nut, which passes through an opening 3 in. diameter and over 1¼ in.; 1¼-in. nut, which passes through a 1¼-in. diameter opening and over a ¾-in. diameter opening; ¾-in. nut, which passes through a ¾-in. diameter opening and over a ⅝-in. diameter opening.

(*H*) Screenings; that which passes through a 1¼-in. diameter opening.

(*I*) Washed sizes; those passing through or over the circular openings of the following diameters, in inches:

Number.	Through.	Over.
1	3	1¾
2	1¾	1⅛
3	1⅛	¾
4	¾	¼
5	¼	

*This and the following two articles are condensed from the appendix of the Boiler Test Code of 1915.

FURNACE EFFICIENCY

Attempts have been made to separate the combined efficiency of boiler, furnace, and grate into two parts, viz., efficiency due to boiler alone, and efficiency due to furnace (including grate), but there is no agreement as to the exact line of demarcation to be used in separating one from the other.

The heat losses chargeable to the furnace alone are clearly those designated *a*, *b*, *c* and *d* in the following list:

a. The loss due to unburned solid fuel dropping through the grates or withdrawn from the furnace, including the solid combustible matter in the cinders, sparks, flue dust, etc.

b. Loss due to the production of CO instead of CO_2.

c. Loss due to escape of unburned volatile hydrocarbons.

d. Loss due to the combination of carbon and moisture and production of hydrogen (by the reaction $C+H_2O=CO+2H$) when fresh moist coal is thrown on a bed of white hot coke.

The remaining heat losses, which are those due to heat carried away by the air and moisture in the escaping gases, loss from radiation, and losses unaccounted for, may be divided as given below in Items *e* to *j*.

e. Moisture losses; embracing evaporation of moisture and heating of steam thus formed to T_p (T_p = temperature corresponding to boiler pressure).

1. Moisture in air.
2. Moisture in coal.
3. Moisture due to burning of hydrogen in the fuel.

f. Moisture losses, consisting in the further heating of steam of Item 3 from T_p to T_g (T_g = temperature of escaping gases).

1. Moisture in coal.
2. Moisture in air.
3. Moisture due to H.

g. Theoretical air supply losses.

1. Heated to T_p.
2. Heated from T_p to T_g.

h. Excess air supply losses.

1. Heated to T_p.
2. Heated from T_p to T_g.

i. Radiation.

1. Due to furnace.
2. Due to boiler.

j. Unaccounted for losses.

1. Due to furnace.
2. Due to boiler.

It has been suggested that these losses be grouped and apportioned as follows:

U = unavoidable losses = $e_1+e_2+e_3+g_1$;
F = furnace losses = $a+b+c+d+i_1+j_1$;
B = boiler losses = $f_1+f_2+f_3+g_2+h_1+h_2+i_2+j_2$;

in which case the individual efficiencies are

$$\text{Maximum theoretical efficiency} = \frac{100-U}{100};$$

$$\text{Furnace efficiency} = \frac{100-(U+F)}{100-U};$$

$$\text{Boiler efficiency} = \frac{100-(U+F+B)}{100-(U+F)};$$

$$\text{Combined efficiency of boiler, furnace and grate} = \frac{100-(U+F+B)}{100}.$$

These formulæ do not, however, furnish a method of determining the true individual efficiencies desired, because it is impossible to determine Item *d*, and impracticable to obtain Item *c* with the gas-testing appliances ordinarily available. It is impossible also to separate the losses i_1 and j_1 attributed to the furnace, from the boiler losses alone due to radiation and those unaccounted for.

Another suggestion is to transfer the excess air loss h_1 to the group of furnace losses F; but this makes the matter even worse, inasmuch as the furnace efficiency is then dependent on the steam pressure in the boiler, which is a matter foreign to any furnace condition. It further assumes that the flue gases cannot be cooled below the temperature due to the pressure, which although true for many types of boiler, is not true in cases where the contra-flow principle is used.

A third method suggested is to include among the boiler losses all those which have been classed as unavoidable above. By this method the furnace efficiency is

$$\frac{100-F}{100},$$

and the boiler efficiency

$$\frac{100-(U+B+F)}{100-F}.$$

If it is desirable to divide the combined efficiency between boiler and furnace in some such manner as those suggested, the method of division employed should be clearly stated.

CALCULATION OF HEAT BALANCE FOR BOILER TEST

The following example shows the method to be employed in computing the various quantities in the heat balance table.

Data.—Semi-bituminous coal, 2 per cent moisture, 8 per cent ash, 90 per cent combustible, 82 per cent C, 4 per cent H, 3 per cent O, 1 per cent N.

B.T.U. per pound combustible 15,800; per pound coal as fired, 14,220. Ash and refuse by boiler test, 13 per cent, referred to coal as fired. The 13 per cent ash and refuse is assumed to contain the 8 per cent of ash shown by the analysis and the 5 per cent of combustible.

Efficiency of boiler, furnace, and grate, based on coal as fired, 70 per cent.

The gas analysis shows that 20 lb. of air is supplied per pound of C burned; and that 0.05 lb. of C was burned to CO per pound of of carbon burned.

The air is supplied at 92 deg. F., and contains 0.02 lb. of water vapor per pound of dry air (60 per cent relative humidity). Flue gas temperature 592 deg. F.

Water from and at 212 deg. per pound coal as fired 10.258; dry coal 10.467; combustible 12.068.

If the fuel lost in ash and refuse is not the combustible of the original coal, but coke or carbon of a heating value of 14,600 B.T.U. per pound, then the heat loss due to it is $0.05 \times 14,600 = 730$ instead of 790 B.T.U. The heating value per pound of combustible burned would then be $(14,220 - 730) \div 0.85 = 15,870$ instead of 15,800. The percentage figures in the last column would be changed accordingly, and the efficiency of the boiler and furnace would be $(11,711 \div 15,870) = 73.78$ per cent instead of 74.1 per cent.

In this table the calculations expressed in the text (excepting Item *a*) refer to the quantities given in the first column, which are based on coal as fired. The quantities in the second column, which are based on dry coal, are obtained from those in the first column by dividing each one by

$$\frac{100-2}{100} = 0.98.$$

The items are designated the same as those given in the tabular form of the report under Item 55.

	B.T.U. per Pound.			Combustible.	
	Coal as Fired.	Dry Coal.	Per Cent.	B.T.U.	Per Cent.
a. Heat absorbed by the boiler (Item 39, 40 or 41 $\times$970.4)	9,954	10,157	70	11,711	74.1
b. Loss due to evaporation of moisture in coal, 0.02 $\times$ (212 $-$ 92) + 970 + 0.47(592 $-$ 212)	25	26	0.2	29	0.2
c. Loss due to heat carried away by steam formed by the burning of hydrogen 0.04 $\times$ 9 $\times$ (120 + 970 + 0.47 $\times$ 380)	457	466	3.2	538	3.4
d. Loss due to heat carried away in the dry flue gases, 21 lb. per lb. C = 21 $\times$ 0.77 = 16.17 $\times$ 500 $\times$ 0.24	1,940	1,979	13.7	2,282	14.4
e. Loss due to carbon monoxide, 0.05 $\times$ 0.77 = 0.0385 C per pound coal $\times$ 10.150	391	399	2.7	460	2.9
f. Loss due to combustible in ash and refuse, 0.05 $\times$ 15,800	790	806	5.6	.....	.....
g. Loss due to heating moisture in air, 0.02 $\times$ 20 $\times$ 0.77 $\times$ 500 $\times$ 0.47	72	74	0.5	86	0.5
h. Loss due to unconsumed hydrogen and hydrocarbons, to radiation, and unaccounted for	591	603	4.1	694	4.5
i. Total calorific value of 1 lb. of coal, as fired, dry coal, or combustible (Lines 42 and 43 and footnote)	14,220	14,510	100.00	15,800	100.0

DETERMINING THE MOISTURE IN COAL *

Until recently two methods of determining moisture in coal have been in common use: first, the one usually adopted in boiler-testing, which consists in drying a large sample, 50 lb. or more, in a shallow pan placed over the boiler or flue; second, the method usually followed by chemists, of drying a 1-gram sample of pulverized coal at 212 deg. Fahr., or a little above, for an hour, or until constant weight is obtained. Both methods are liable to large errors. In the first method, the temperature at which the drying takes place is uncertain, and there is no means of knowing whether the temperature obtained is sufficient to drive off the moisture that is held by capillary force or other attraction within the lumps of coal, which, at least in case of bituminous coals seems to be as porous as wood, and as capable of absorbing moisture from the atmosphere. The second method is liable to greater errors in sampling than the first, and during the process of fine crushing and passing through sieves, a considerable portion of the moisture is apt to be removed by air-drying. In an extensive series of boiler-tests made by the writer in the summer of 1896, it became necessary to find more accurate means of determining moisture than either of those above described. It was found by repeated heating at gradually increasing temperatures from 212 up to 300 deg. or over, and weighing at intervals of an hour or more, that the weight of coal continually decreased until it became nearly constant, and then a very slight increase took place, which increase became greater on further repeated heatings to temperatures above 250 deg. It has often been stated that if coal is heated above 212 deg. Fahr., volatile matter will be driven off; but repeated tests on seventeen different varieties of coal mined in western Pennsylvania, Ohio, Indiana, Illinois, and Kentucky invariably showed a gradual decrease of weight to a minimum, followed by the increase, as stated above, and in no single case was there any perceptible odor or other indication of volatile matter passing off below a temperature of 350 deg. The fact that no volatile matter was given off was further proved by heating the coal in a glass retort and catching the vapor driven off in a bottle filled with water and inverted in a basin; the air displaced from the retort by expansion due to the heating displacing the water in the bottle. When the retort was cooled, after being heated to 350 deg. in an oil bath, the air thus expanded contracted, and returned from the bottle to the retort, leaving the bottle full of water, as at the beginning of the heating, showing that no gas had been given off, except possibly such exceedingly small amount as might be absorbed by the water. The method described in Section XV of the report† was then adopted as the best available method of determining the moisture in these coals. Its accuracy was further checked by other methods.‡

The new method of drying and its results were communicated by the writer to Prof. R. C. Carpenter of Cornell University, shortly after they were made and he thereupon began experimenting with the method, and fully confirmed

* This and following articles are from the signed appendices to the Code of 1899, somewhat abridged. The initials are those of Geo. H. Barrus, J. C. Hoadley, and William Kent.

† The same method is recommended in the Report of the Power Test Committee in 1915.

‡ For scientific investigations in which extreme accuracy is desired, the author would suggest that the coal be dried in an atmosphere of nitrogen to avoid oxidation, and that the moisture driven off be absorbed by chloride of calcium and weighed. The loss of weight by the coal should equal the gain of weight by the chloride of calcium if no volatile matter is driven off.

the writer's conclusions. In a letter dated May 18, 1897, he says: "We have investigated the moisture question, and find that in all the samples tested, some four or five in number, there is no appreciable loss between temperatures 250 and 350 deg.; at least the loss is less than our means of weighing." In his paper on "Hygrometric Properties of Coals," presented at the Hartford meeting (Transactions, vol. xviii, p. 948), he says:

"With the most volatile coals, there is no sensible loss of weight due to driving off the volatile matter under a temperature of 380 deg. Fahr., and with an anthracite coal there is no sensible loss under a temperature of 700 deg. Fahr." W. K.

DETERMINATION OF THE MOISTURE IN THE STEAM

The throttling steam calorimeter,* first described by Professor Peabody in Trans. A.S.M.E., vol. x, page 327, and its modifications by Mr. Barrus, vol. xi, page 790; vol. xvii, page 617; and by Professor Carpenter, vol. xii, page 840; also the separating calorimeter designed by Professor Carpenter, vol. xvii, page 608; which instruments are used to determine the moisture existing in a small sample of steam taken from the steam-pipe, give results, when properly handled, which may be accepted as accurate within 0.5 per cent (this per cent being computed on the total quantity of the steam) for the sample taken. The possible error of 0.5 per cent is the aggregate of the probable error of careful observation, and of the errors due to inaccuracy of the pressure-gages and thermometers, to radiation, and, in the case of the throttling calorimeter, to the possible inaccuracy of the figure 0.46 for the specific heat of superheated steam, which is used in computing the results. It is, however, by no means certain that the sample represents the average quality of the steam in the pipe from which the sample is taken. The practical impossibility of obtaining an accurate sample, especially when the percentage of moisture exceeds 2 or 3 per cent, is shown in the two papers by Professor Jacobus in Transactions, vol. xvi, pages 448, 1017.

In trials of the ordinary forms of horizontal shell and of water-tube boilers, in which there is a large disengaging surface, when the water-level is carried at least 10 in. below the level of the steam outlet, and when the water is not of a character to cause foaming, and when in the case of water-tube boilers the steam outlet is placed in the rear of the middle of the length of the water-drum, the maximum quantity of moisture in the steam rarely, if ever, exceeds 2 per cent; and in such cases a sample taken with the precautions specified in the Code may be considered to be an accurate average sample of the steam furnished by the boiler, and its percentage of moisture as determined by the throttling or separating calorimeter may be considered as accurate within

* The throttling calorimeter is based on the fact that steam containing a small percentage of moisture is dried by throttling and superheated to a temperature above that due to its reduced pressure. It consists essentially of ½-in. pipe fittings containing a flange coupling in which is inserted a thin blank flange or disk perforated with a hole ⅛ in. or less in diameter. The steam from the sampling pipe passes through this hole into a small exhaust chamber fitted with a mercury well and thermometer. The difference between the temperature of the throttled steam, as shown by this thermometer and that due to its pressure (subject to a slight correction for radiation) is the superheating, and from this the moisture is calculated by a formula which is based on the principle that the total heat of the moist steam before throttling is the same as that of the dry steam after throttling if there is no loss or gain of heat by radiation or conduction. To lessen the transfer of heat by conduction, asbestos washers should be placed on each side of the disk, and to lessen radiation the whole instrument should be enclosed in a non-conducting covering.

½ of 1 per cent. For scientific research, and in all cases in which there is reason to suspect that the moisture may exceed 2 per cent, a steam separator should be placed in the steam-pipe, as near to the steam outlet of the boiler as convenient, well covered with felting, all the steam made by the boiler passing through it, and all the moisture caught by it carefully weighed after being cooled. A convenient method of obtaining the weight of the drip from the separator is to discharge it through a trip into a barrel of cold water standing on a platform scale. A throttling or a separating calorimeter should be placed in the steam-pipe, just beyond the steam separator, for the purpose of determining, by the sampling method, the small percentage of moisture which may still be in the steam after passing through the separator.

The formula for calculating the percentage of moisture when the throttling calorimeter is used is the following:

$$w = 100 \times \frac{H - h - k(T - t)}{L},$$

in which w = percentage of moisture in the steam, H = total heat, and L = latent heat per pound of steam at the pressure in the steam-pipe, h = total heat per pound of steam at the pressure in the discharge side of the calorimeter, k = specific heat of superheated steam, T = temperature of the throttle and superheated steam in the calorimeter, and t = temperature due to the pressure in the discharge side of the calorimeter, = 212 deg. Fahr., at atmospheric pressure. Taking $k = 0.46$ and $t = 212$, the formula reduces to

$$w = 100 \times \frac{H - 1150.4 - 0.46(T - 212)}{L}.$$

W. K.

EFFICIENCY OF THE BOILER

The efficiency of the boiler, not including the grate (or the efficiency based upon combustible) is a more accurate measure of comparison of different boilers than the efficiency including the grate (or the efficiency based upon coal); for the latter is subject to a number of variable conditions, such as size and character of the coal, air-spaces between the grate-bars, skill of the fireman in saving coal from falling through the grate, etc. It is, moreover, subject to errors of sampling the coal for drying and for analysis, which affect the result to a greater degree than they do the efficiency based upon combustible, for the reason that the heating value per pound of combustible of any sample selected from a given lot, such as a car-load of coal is practically a constant quantity and is independent of the percentage of moisture and ash in the sample; while the sample itself, upon the heating value of which the efficiency based on coal is calculated, may differ in its percentage of moisture and ash and from the average coal used in the boiler-test.

When the object of a boiler-test is to determine its efficiency as an absorber of heat, or to compare it with other boilers, the efficiency based on combustible is the one which should be used, but when the object of the test is to determine the efficiency of the combination of the boiler, the furnace, and the grate, the efficiency based on coal must necessarily be used.

W. K.

SAMPLING FLUE GASES

Very great diversities in the composition of flue gases often exist in the same flue at the same time. To obtain a fair sample, it has been found suf-

ficient to have one orifice to draw off gases through for each 25 sq.in. of cross-section of flue. The pipes must be of equal diameter and of equal length. One-quarter-in. gas pipes, all alike at the ends, and of equal lengths, answer well. Similar steel tubes will be still better (because smoother and more uniform). These should be secured in a box of block of galvanized sheet iron, equal in thickness to one course of brick, in such a manner that the open ends may be evenly distributed over the area of the flue *A* (Fig. 65), and their other open enclosed in the receiver *B*. If the flue gases be drawn off from the receiver *B* by four tubes, *CC*, into a mixing-box *D* beneath, about 3-in. cube, a good mixture can be obtained. Two such "samplers," one above the other a foot apart, in the same flue, will furnish samples of gases which show by analysis the same composition.

J. C. H.

STARTING AND STOPPING A TEST

A special caution is needed against a modification of the "alternate" method,* which has been adopted by some testing engineers within the past few years. It consists in taking the starting and the stopping times each at a time subsequent to the cleaning, say after 400 lb. of coal has been fired since the cleaning. There are two sources of serious error in this method, one causing an incorrect measurement of the coal, the other an incorrect measurement of the water. Suppose 200 lb. of hot coke are left on the grate at the end of cleaning and 400 lb. of fresh coal are added by the end of, say, half an hour after cleaning. If the coal left at the end of the cleaning, and the boiler walls also, are very hot, and the coal is highly volatile and dry and the pieces of such size as not to choke the air-supply, the fire may burn so briskly that at the end of the half-hour the fuel-value of the partly-burned coal left out of the total 600 lb. is equivalent only to 200 lb. of coal. If, on the contrary, the hot coke on the grates at the end of the cleaning, and the boiler walls, are considerably cooled, if the fresh coal fired is moist and of small size, such as the slack of run-of-mine bituminous coal, which is often found in one portion of a pile in greater quantity than in another, the fire during the half-hour may burn so sluggishly that the coal and coke on the grate at the end of the half-hour may have a fuel-value equal to 400 lb. of coal. If, in this case, it is assumed that the quantity and condition of the coal at the end of the half-hour after cleaning are the same at the starting and stopping time; and, if the fire burned briskly during the half-hour before starting and slowly during the half-hour before stopping, the boiler will be charged with more coal than was actually burned. If, on the contrary, the coal burns away more slowly during the half-hour after the cleaning before the starting time and more rapidly during the half-hour before the end of the test, the boiler is not charged with as much coal as was actually burned.

The error in water-measurement is due to the fact that the condition of the fire, and especially the quantity of flaming gases arising from it, influences the height of the water-level. A bright hot fire, or a fire with an abundance of burning gas proceeding from it, causes the water-level to rise; while anything that cools the furnace, such as freshly-fired coal, an open fire-door, or a check to the draft, causes the water-level to fall. A rise or a fall of several

* The "alternate" method of the Code of 1899 is the standard method of the Code of 1915. The old standard method, which consisted in starting with a wood fire and stopping by burning down and withdrawing all ash and unburned coal from the grate, is now abandoned.

inches in a few seconds frequently occurs, when bituminous coal is used. If the water-level is noted at the starting of the test, when it is raised by a bright fire, and at the end of a test, when it is depressed by the stoppage of violent ebullition or of rapid circulation, due to the cooling of the fire, the boiler will be credited with more water than was really evaporated and *vice versa*.

The only correct times to be noted as the starting and the stopping times are when the smallest amount of fuel is on the grate and when it is in the most burned-out condition; that is, just before firing fresh coal after cleaning, and when the water-level is in its most quiet condition and the least raised by ebullition. The furnace-door has then been kept open for some time for cleaning and the furnace therefore is in its coolest state. This condition of fire and of water-level can be duplicated immediately after cleaning the fire; but there is no certainty of duplication of any condition when there is a bright fire and consequent rapid steaming.

These statements are not based upon theoretical considerations, but are the results of many experiments made by the writer to determine the best starting and stopping times. In a long series of tests with bituminous coals no less than six different times were recorded as starting times and as many as stopping times, and the coal apparently used and the water apparently evaporated recorded and calculated for each. These times were: *A*, before opening the first or right-hand door to clean the fire; *B*, after cleaning the first half of the furnace and just before firing fresh coal; *C*, after cleaning the second half of the furnace; *D*, after 200 lb. of fresh coal had been fired; *E*, after 400 lb.; *F*, after 600 lb. By plotting the apparent water-evaporation between *A* and *E*, both for starting and for stopping times, it was seen that there was nearly always an apparent negative evaporation between *B* and *D*, and sometimes between *B* and *C* and between *B* and *E*, due to the correction for height of observed water-level, the level rising rapidly, being much greater than the water fed by the pump. There was often no similarity of appearance of the plotted diagrams between *A* and *F* at the beginning and at the end of the same test. The possible error of water-measurement due to taking *A*, *D*, *E*, or *F* as the starting time was sometimes as much as 2000 lb. of water, or about 3 per cent of the whole amount evaporated in a ten-hour test. The record of water evaporated between the stopping and starting times *C* occasionally differed considerably from that taken between the *B* start and stop, due to the fact that sometimes between *B* and *C* there was a sudden lighting up of the fresh coal on the cleaned side of the furnace, while at other times the fire would not light up brightly until after the *C* point had passed. It was therefore decided that the *B* time, when the furnace was the coldest and the water-level at the lowest, was the only time which could be accepted as the true starting and stopping time.

W. K.

TABLE 1

FACTORS OF EVAPORATION FOR DRY SATURATED STEAM

Lb.							
Gage press.. 0.3	10.3	20.3	30.3	40.3	50.3	60.3	70.3
Abs. press. 15	25	35	45	55	65	75	85
Feed Water.	Factors of Evaporation.						
212° F.	1.0003	1.0103	1.0169	1.0218	1.0258	1.0290	1.0316	1.0340
209	34	34	1.0200	50	89	1.0321	47	71
206	65	65	31	81	1.0320	52	79	1.0402
203	96	96	62	1.0312	51	83	1.0410	33
200	1.0127	1.0227	93	43	82	1.0414	41	64
197	58	58	1.0324	74	1.0413	45	72	95
194	89	89	55	1.0405	44	76	1.0503	1.0526
191	1.0220	1.0320	86	36	75	1.0507	34	57
188	51	51	1.0417	67	1.0506	38	65	88
185	82	82	48	98	37	69	96	1.0619
182	1.0313	1.0413	79	1.0529	68	1.0600	1.0627	50
179	44	44	1.0510	60	99	31	58	81
176	75	75	41	91	1.0630	62	89	1.0712
173	1.0406	1.0506	72	1.0622	61	93	1.0720	43
170	37	37	1.0603	53	92	1.0724	51	74
167	68	68	34	84	1.0723	55	82	1.0805
164	99	99	65	1.0715	54	86	1.0812	36
161	1.0530	1.0630	96	85	85	1.0817	43	67
158	61	61	1.0727	76	1.0816	47	74	98
155	92	92	58	1.0807	46	78	1.0905	1.0929
152	1.0623	1.0723	89	38	77	1.0909	36	60
149	54	54	1.0820	69	1.0908	40	67	91
146	85	85	51	1.0900	39	71	98	1.1022
143	1.0715	1.0815	81	31	70	1.1002	1.1029	52
140	46	46	1.0912	62	1.1001	33	60	83
137	77	77	43	93	32	64	91	1.1114
134	1.0808	1.0908	74	1.1023	63	95	1.1121	45
131	39	39	1.1005	54	93	1.1125	52	76
128	70	70	36	85	1.1124	56	83	1.1207
125	1.0901	1.1001	67	1.1116	55	87	1.1214	38
122	31	31	97	47	86	1.1218	45	69
119	62	62	1.1128	78	1.1217	49	76	99
116	93	93	59	1.1209	48	80	1.1306	1.1330
113	1.1024	1.1124	90	39	79	1.1310	37	61
110	55	55	1.1221	70	1.1309	41	68	92
107	86	86	52	1.1301	40	72	99	1.1423
104	1.1116	1.1216	82	32	71	1.1403	1.1430	53
101	47	47	1.1313	63	1.1402	34	61	84
98	78	78	44	93	33	65	91	1.1515
95	1.1209	1.1309	75	1.1424	63	95	1.1522	46
92	40	40	1.1406	55	94	1.1526	53	77
89	71	71	37	86	1.1525	57	84	1.1608
86	1.1301	1.1401	67	1.1518	56	88	1.1615	38
83	32	32	98	48	87	1.1619	46	69
80	63	63	1.1529	78	1.1618	50	76	1.1700
77	94	94	60	1.1609	48	80	1.1707	31
74	1.1425	1.1525	91	40	79	1.1711	38	62
71	55	55	1.1621	71	1.1710	42	69	92
68	86	86	52	1.1702	41	73	1.1800	1.1823
65	1.1517	1.1617	83	33	72	1.1804	30	54
62	48	48	1.1714	63	1.1803	35	61	85
59	79	79	45	94	33	65	92	1.1916
56	1.1610	1.1710	76	1.1825	64	96	1.1923	47
53	41	41	1.1807	56	95	1.1927	54	78
50	72	72	38	87	1.1926	58	85	1.2009
47	1.1703	1.1803	69	1.1918	57	89	1.2016	40
44	34	34	1.1900	49	88	1.2020	47	71
41	65	65	31	80	1.2019	51	78	1.2102
38	96	96	62	1.2011	50	82	1.2109	33
35	1.1827	1.1927	93	42	81	1.2113	40	64
32	58	58	1.2024	73	1.2113	44	71	95

TABLE 1—*Continued*

FACTORS OF EVAPORATION FOR DRY SATURATED STEAM

Gage press. Lb. / Abs. press.	80.3 / 95	85.3 / 100	90.3 / 105	95.3 / 110	100.3 / 115	105.3 / 120	110.3 / 125	115.3 / 130
Feed Water.	Factors of Evaporation.							
212° F.	1.0361	1.0370	1.0379	1.0387	1.0396	1.0404	1.0411	1.0418
209	92	1.0401	1.0410	1.0419	1.0427	35	42	49
206	1.0423	32	41	50	58	66	73	81
203	54	63	72	81	89	97	1.0504	1.0512
200	85	94	1.0504	1.0512	1.0520	1.0528	35	43
197	1.0516	1.0525	35	43	51	59	66	74
194	47	56	66	74	82	90	97	1.0605
191	78	87	97	1.0605	1.0613	1.0621	1.0629	36
188	1.0609	1.0618	1.0628	36	44	52	60	67
185	40	49	59	67	75	83	91	98
182	71	80	90	98	1.0706	1.0714	1.0721	1.0729
179	1.0702	1.0711	1.0721	1.0729	37	45	52	60
176	33	42	52	60	68	76	83	91
173	64	73	82	91	99	1.0807	1.0814	1.0822
170	95	1.0804	1.0813	1.0822	1.0830	38	45	53
167	1.0826	35	44	53	61	69	76	84
164	57	66	75	84	92	1.0900	1.0907	1.0914
161	88	97	1.0906	1.0914	1.0923	31	38	45
158	1.0919	1.0928	37	45	54	62	69	76
155	50	59	68	76	85	93	1.1000	1.1007
152	80	90	99	1.1007	1.1015	1.1024	31	38
149	1.1011	1.1021	1.1030	38	46	55	62	69
146	42	52	61	69	77	86	93	1.1100
143	73	82	92	1.1100	1.1108	1.1116	1.1124	31
140	1.1104	1.1113	1.1123	31	39	47	54	62
137	35	44	53	62	70	78	85	93
134	66	75	84	93	1.1201	1.1209	1.1216	1.1223
131	97	1.1206	1.1215	1.1223	32	40	47	54
128	1.1227	37	46	54	62	71	78	85
125	58	68	77	85	93	1.1302	1.1309	1.1316
122	89	98	1.1308	1.1316	1.1324	32	40	47
119	1.1320	1.1329	39	47	55	63	70	78
116	51	60	69	78	86	94	1.1401	1.1408
113	82	91	1.1400	1.1408	1.1417	1.1425	32	39
110	1.1412	1.1422	31	39	47	56	63	70
107	43	53	62	70	78	87	94	1.1501
104	74	83	92	1.1501	1.1509	1.1517	1.1525	32
101	1.1505	1.1514	1.1523	32	40	48	55	63
98	36	45	54	62	71	79	86	93
95	66	76	85	93	1.1602	1.1610	1.1617	1.1624
92	97	1.1607	1.1616	1.1624	32	41	48	55
89	1.1628	37	47	55	63	71	79	86
86	59	68	78	86	94	1.1702	1.1710	1.1717
83	90	99	1.1708	1.1717	1.1725	33	40	48
80	1.1721	1.1730	39	47	56	64	71	78
77	51	61	70	78	86	95	1.1802	1.1809
74	82	92	1.1801	1.1809	1.1817	1.1826	33	40
71	1.1813	1.1822	32	40	48	56	64	71
68	44	53	62	71	79	87	94	1.1902
65	75	84	93	1.1902	1.1910	1.1918	1.1925	33
62	1.1906	1.1915	1.1924	32	41	49	56	63
59	37	46	55	63	72	80	87	94
56	67	77	86	94	1.2002	1.2011	1.2018	1.2025
53	98	1.2008	1.2017	1.2025	33	42	49	56
50	1.2029	39	48	56	64	73	80	87
47	60	70	79	87	95	1.2104	1.2111	1.2118
44	91	1.2101	1.2110	1.2118	1.2126	35	42	49
41	1.2122	32	41	49	57	66	73	80
38	53	63	72	80	88	97	1.2204	1.2211
35	84	94	1.2203	1.2211	1.2219	1.2228	35	42
32	1.2216	1.2225	34	42	51	59	66	73

TABLE 1—*Continued*

FACTORS OF EVAPORATION FOR DRY SATURATED STEAM

Gage press. Lb. / Abs. press.	120.3 / 135	125.3 / 140	130.3 / 145	135.3 / 150	140.3 / 155	145.3 / 160	150.3 / 165	155.3 / 170	160.3 / 175
Feed Water.	FACTORS OF EVAPORATION.								
212° F.	1.0425	1.0431	1.0437	1.0443	1.0449	1.0454	1.0460	1.0464	1.0469
209	56	62	68	74	80	86	91	95	1.0500
206	87	93	99	1.0505	1.0511	1.0517	1.0522	1.0526	31
203	1.0518	1.0524	1.0530	36	43	48	53	57	62
200	49	55	61	67	74	79	84	88	93
197	80	86	92	98	1.0605	1.0610	1.0615	1.0619	1.0624
194	1.0611	1.0617	1.0623	1.0629	36	41	46	50	55
191	42	48	54	60	67	72	77	81	86
188	73	79	85	91	98	1.0703	1.0708	1.0712	1.0717
185	1.0704	1.0710	1.0716	1.0722	1.0729	34	39	43	48
182	35	41	47	53	60	65	70	74	79
179	66	72	78	84	91	96	1.0801	1.0805	1.0810
176	97	1.0803	1.0809	1.0815	1.0822	1.0827	32	36	41
173	1.0828	34	40	46	53	58	63	67	72
170	59	65	71	77	83	89	94	98	1.0903
167	90	96	1.0902	1.0908	1.0914	1.0920	1.0925	1.0929	34
164	1.0921	1.0927	33	39	45	51	56	60	65
161	52	58	64	70	76	81	87	91	96
158	82	89	95	1.1001	1.007	1.1012	1.1018	1.1022	1.1027
155	1.1013	1.1020	1.1026	32	38	43	48	53	58
152	44	51	57	63	69	74	79	83	89
149	75	81	88	94	1.1100	1.1105	1.1110	1.1114	1.1120
146	1.1106	1.1112	1.1119	1.1125	31	36	41	45	50
143	37	43	49	56	62	67	72	76	81
140	68	74	80	86	93	98	1.1203	1.1207	1.1212
137	99	1.1205	1.1211	1.1217	1.1224	1.1229	34	38	43
134	1.1230	36	42	48	54	59	65	69	74
131	60	67	73	79	85	90	95	1.1300	1.1305
128	91	98	1.1304	1.1310	1.1316	1.1321	1.1326	30	36
125	1.1322	1.1328	35	41	47	52	57	61	66
122	53	59	65	71	78	83	88	92	97
119	84	90	96	1.1402	1.1409	1.1414	1.1419	1.1423	1.1428
116	1.1415	1.1421	1.1427	33	39	45	50	54	59
113	45	52	58	64	70	75	81	85	90
110	76	82	89	95	1.1501	1.1506	1.1511	1.1515	1.1521
107	1.1507	1.1513	1.1519	1.1526	32	37	42	46	51
104	38	44	50	56	63	68	73	77	82
101	69	75	81	87	93	99	1.1604	1.1608	1.1613
98	1.1600	1.1606	1.1612	1.1618	1.1624	1.1629	35	39	44
95	30	37	43	49	55	60	65	70	75
92	61	67	74	80	86	91	96	1.1700	1.1705
89	92	98	1.1704	1.1711	1.1717	1.1722	1.1727	31	36
86	1.1723	1.1729	35	41	48	53	58	62	67
83	54	60	66	72	78	84	89	93	98
80	85	91	97	1.1803	1.1809	1.1814	1.1820	1.1824	1.1829
77	1.1815	1.1822	1.1828	34	40	45	50	54	60
74	46	52	59	65	71	76	81	85	90
71	77	83	89	96	1.1902	1.1907	1.1912	1.1916	1.1921
68	1.1908	1.1914	1.1920	1.1926	33	38	43	47	52
65	39	45	51	57	68	69	74	78	83
62	70	76	82	88	94	99	1.2005	1.2009	1.2014
59	1.2000	1.2007	1.2013	1.2019	1.2025	1.2030	35	40	45
56	31	38	44	50	56	61	66	70	76
53	62	68	75	81	87	92	97	1.2101	1.2107
50	93	99	1.2106	1.2112	1.2118	1.2123	1.2128	32	37
47	1.2124	1.2130	37	43	49	54	59	63	68
44	55	61	68	74	80	85	90	94	1.2200
41	86	92	99	1.2205	1.2211	1.2216	1.2221	1.2225	31
38	1.2217	1.2223	1.2230	36	42	47	52	56	62
35	48	55	61	67	73	78	83	88	93
32	79	86	92	98	1.2340	1.2309	1.2315	1.2319	1.2324

TABLE 1—*Continued*

FACTORS OF EVAPORATION FOR DRY SATURATED STEAM

Lb. Gage press. / Abs. press.	165.3 / 180	170.3 / 185	175.3 / 190	180.3 / 195	185.3 / 200	190.3 / 205	195.3 / 210	200.3 / 215	205.3 / 220
Feed Water.	Factors of Evaporation.								
212° F.	1.0474	1.0478	1.0483	1.0487	1.0492	1.0496	1.0499	1.0503	1.0507
209	1.0505	1.0509	1.0514	1.0519	1.0523	1.0527	1.0530	34	38
206	36	40	45	50	54	58	61	65	69
203	67	71	77	81	85	89	92	96	1.0600
200	98	1.0602	1.0608	1.0612	1.0616	1.0620	1.0623	1.0627	31
197	1.0629	33	39	43	47	51	54	58	62
194	60	64	70	74	78	82	85	89	93
191	91	95	1.0701	1.0705	1.0709	1.0713	1.0716	1.0720	10.724
188	1.0722	1.0727	32	36	40	44	47	51	55
185	53	58	63	67	71	75	78	82	86
182	84	88	94	98	1.0802	1.0806	1.0809	1.0813	1.0817
179	1.0815	1.0819	1.0825	1.0829	33	37	40	44	48
176	46	50	56	60	64	68	71	75	79
173	77	81	87	91	95	99	1.0902	1.0906	1.0910
170	1.0908	1.0912	1.0917	1.0922	1.0926	1.0930	33	37	41
167	39	43	48	53	57	61	64	68	72
164	70	74	79	84	88	92	95	99	1.1003
161	1.1001	1.1005	1.1010	1.1014	1.1019	1.1023	1.1026	1.1030	34
158	32	36	41	45	49	54	57	61	65
155	63	67	72	76	80	85	88	92	96
152	94	98	1.1103	1.1107	1.1111	1.1115	1.1119	1.1123	1.1127
149	1.1125	1.1129	34	38	42	46	49	54	58
146	56	60	65	69	73	77	80	84	89
143	86	91	96	1.1200	1.1204	1.1208	1.1211	1.1215	1.1219
140	1.1217	1.1221	1.1227	31	35	39	42	46	50
137	48	52	58	62	66	70	73	77	81
134	79	83	88	92	97	1.1301	1.1304	1.1308	1.1312
131	1.1310	1.1314	1.1319	1.1323	1.1327	32	35	39	43
128	41	45	50	54	58	62	66	70	74
125	72	76	81	85	89	93	96	1.1400	1.1405
122	1.1402	1.1407	1.1412	1.1416	1.1420	1.1424	1.1428	31	35
119	33	37	43	47	51	55	57	62	66
116	64	68	73	78	82	86	89	93	97
113	95	99	1.1504	1.1508	1.1512	1.1515	1.1520	1.1524	1.1528
110	1.1526	1.1530	35	39	43	47	50	55	59
107	57	61	66	70	74	78	81	85	90
104	87	92	97	1.1601	1.1605	1.1609	1.1612	1.1616	1.1620
101	1.1618	1.1622	1.1627	32	36	40	43	47	51
98	49	53	58	62	67	71	74	78	82
95	80	84	89	93	97	1.1701	1.1705	1.1709	1.1713
92	1.1711	1.1715	1.1720	1.1724	1.1728	32	35	39	44
89	42	46	51	55	59	63	66	70	75
86	72	76	82	86	90	94	97	1.1801	1.1805
83	1.1803	1.1807	1.1812	1.1817	1.1821	1.1825	1.1828	32	36
80	34	38	43	47	52	56	59	63	67
77	65	69	74	78	82	86	90	94	98
74	96	1.1900	1.1905	1.1909	1.1913	1.1917	1.1920	1.1924	1.1929
71	1.1926	31	36	40	44	48	51	55	59
68	57	61	67	71	75	79	82	86	90
65	88	92	97	1.2002	1.2006	1.2010	1.2013	1.2017	1.2021
62	1.2019	1.2023	1.2028	32	36	41	44	48	52
59	50	54	59	63	67	72	75	79	83
56	81	85	90	94	98	1.2102	1.2106	1.2110	1.2114
53	1.2112	1.2116	1.2121	1.2125	1.2129	33	36	41	45
50	43	47	52	56	60	64	67	71	76
47	74	78	83	87	91	95	98	1.2202	1.2207
44	1.2205	1.2209	1.2214	1.2218	1.2222	1.2226	1.2229	34	38
41	36	40	45	49	53	57	60	65	69
38	67	71	76	80	84	88	91	96	1.2300
35	98	1.2302	1.2307	1.2311	1.2315	1.2320	1.2323	1.2327	31
32	1.2329	33	38	42	46	51	54	58	62

TABLE 1—*Continued*

FACTORS OF EVAPORATION FOR DRY SATURATED STEAM

Gage press. Lb. / Abs. press.	210.3 225	215.3 230	220.3 235	225.3 240	230.3 245	235.3 250	240.3 255	245.3 260	250.3 265
Feed Water.	Factors of Evaporation.								
212° F.	1.0510	1.0513	1.0517	1.0520	1.0523	1.0527	1.0529	1.0533	1.0535
209	41	44	48	52	55	58	60	64	66
206	72	75	79	83	86	89	91	95	97
203	1.0603	1.0606	1.0611	1.0614	1.0617	1.0620	1.0622	1.0626	1.0629
200	34	37	42	45	48	51	53	57	60
197	65	68	73	76	79	82	84	88	91
194	96	1.0700	1.0704	1.0707	1.0710	1.0713	1.0715	1.0719	1.0722
191	1.0727	31	35	38	41	44	46	50	53
188	58	62	66	69	72	75	78	81	84
185	89	93	97	1.0800	1.0830	1.0806	1.0809	1.0812	1.0816
182	1.0820	1.0823	1.0828	31	34	37	39	43	45
179	51	54	59	62	65	68	70	74	77
176	82	86	90	93	96	99	1.0901	1.0905	1.0908
173	1.0913	1.0916	1.0921	1.0924	1.0927	1.0930	32	36	39
170	44	47	51	55	58	61	63	67	69
167	75	78	82	86	89	92	94	98	1.1001
164	1.1006	1.1009	1.1013	1.1016	1.1019	1.1023	1.1025	1.1029	31
161	37	40	44	47	50	54	56	60	62
158	68	71	75	78	81	85	87	91	93
155	99	1.1102	1.1106	1.1109	1.1112	1.1115	1.1118	1.1122	1.1124
152	1.1130	33	37	40	43	46	49	53	55
149	61	64	68	71	74	77	80	83	86
146	92	95	99	1.1202	1.1205	1.1208	1.1211	1.1214	1.1217
143	1.1223	1.1226	1.1230	33	36	39	42	45	48
140	53	56	61	64	67	70	72	76	79
137	84	87	92	95	98	1.1301	1.1303	1.1307	1.1310
134	1.1315	1.1318	1.1322	1.1326	1.1329	32	34	38	40
131	46	49	53	56	59	62	65	69	71
128	77	80	84	87	90	93	96	1.1400	1.1402
125	1.1408	1.1411	1.1415	1.1418	1.1421	1.1424	1.1427	30	33
122	39	42	46	49	52	55	58	61	64
119	69	72	77	80	83	86	88	92	95
116	1.1500	1.1503	1.1507	1.1511	1.1514	1.1517	1.1519	1.1523	1.1525
113	31	34	38	41	44	48	50	54	56
110	62	65	69	72	75	78	81	85	87
107	93	96	1.1600	1.1603	1.1606	1.1609	1.1612	1.1615	1.1618
104	1.1624	1.1627	31	34	37	40	43	46	49
101	54	57	61	65	68	71	73	77	80
98	85	88	92	95	98	1.1702	1.1704	1.1708	1.1710
95	1.1716	1.1719	1.1723	1.1726	1.1729	32	35	39	41
92	47	50	54	57	60	63	66	69	72
89	78	81	85	88	91	94	97	1.1800	1.1803
86	1.1808	1.1812	1.1816	1.1819	1.1822	1.1825	1.1827	31	34
83	39	42	46	50	53	56	58	62	64
80	70	73	77	80	83	87	89	93	95
77	1.1901	1.1904	1.1908	1.1911	1.1914	1.1917	1.1920	1.1924	1.1926
74	32	35	39	42	45	48	51	54	57
71	63	66	70	73	76	79	82	85	88
68	93	96	1.2001	1.2004	1.2007	1.2010	1.2012	1.2016	1.2019
65	1.2024	1.2027	31	35	38	41	43	47	49
62	55	58	62	65	68	72	74	78	80
59	86	89	93	96	99	1.2102	1.2105	1.2109	1.2111
56	1.2117	1.2120	1.2124	1.2127	1.2130	33	36	40	42
53	48	51	55	58	61	64	67	70	73
50	79	82	86	89	92	95	98	1.2201	1.2204
47	1.2210	1.2213	1.2217	1.2220	1.2223	1.2226	1.2229	32	35
44	41	44	48	51	54	57	60	63	66
41	72	75	79	82	85	88	91	94	97
38	1.2303	1.2306	1.2310	1.2313	1.2316	1.2319	1.2322	1.2325	1.2328
35	34	37	41	44	47	50	53	57	59
32	65	68	72	75	78	82	84	88	90

TABLE 2

PROPERTIES OF SATURATED STEAM

(Condensed from Goodenough's " Properties of Steam and Ammonia," John Wiley & Sons, by permission.)

Pressure		Temp. Deg. F.,	Volume, cu. ft. per lb.	Weight, lb. per cu. ft.	Heat Content in B.T.U.		Latent heat of vaporization in B.T.U.
In. of mercury	Lb. per sq. in.				of liquid.	of vapor.	
1	.4912	79.06	652	0.001534	47.11	1095.0	1047.9
2	.982	101.17	338.9	0.002950	69.16	1105.1	1036.0
3	1.474	115.08	231.4	0.00432	83.04	1111.4	1028.3
4	1.965	125.44	176.5	0.00566	93.37	1115.9	1022.5
5	2.456	133.78	143.2	0.00698	110.68	1119.6	1017.9
6	2.947	140.80	120.7	0.00829	108.69	1122.6	1013.9
7	3.438	146.88	110.4	0.00958	114.8	1125.2	1010.5
8	3.929	152.26	92.1	0.01085	120.2	1127.5	1007.4
9	4.421	157.10	82.5	0.01212	125.0	1129.6	1004.6
10	4.912	161.50	74.8	0.01338	129.4	1131.4	1002.1
11	5.403	165.55	68.4	0.01463	133.4	1133.1	999 7
12	5.894	169.30	63.0	0.01587	137.2	1134.7	997.5
13	6.39	172.79	58.5	0.01710	140.7	1136.1	995.5
14	6.88	176.06	54.6	0.01833	143.9	1137.5	993.6
15	7.37	179.14	51.14	0.01955	147.0	1138.8	991.7
16	7.86	182.06	48.14	0.02077	149.9	1140.0	990.0
17	8.35	184.83	45.49	0.02198	152.7	1141.1	988.3
18	8.84	187.46	43.12	0.02319	155.4	1142.1	986.7
19	9.33	189.97	40.99	0.02439	157.9	1143.1	985.2
20	9.82	192.38	39.08	0.02559	160.3	1144.1	983.8
21	10.31	194.68	37.34	0.02678	162.6	1145.0	982.4
22	10.81	196.89	35.75	0.02797	164.8	1145.9	981.1
23	11.30	199.03	34.29	0.02916	167.0	1146.7	979.8
24	11.79	201.09	32.95	0.03035	169.0	1147.5	978.5
25	12.28	203.08	31.71	0.03153	170.1	1148.3	977.3
26	12.77	205.00	30.57	0.03271	173.0	1149.1	976.1
27	13.26	206.87	29.51	0.03388	174.8	1149.8	974.9
28	13.75	208.67	28.53	0.03505	176.6	1150.5	973.8
29	14.24	210.43	27.61	0.03622	178.4	1151.2	972.7
29.92	14.697	212	26.81	0.03730	180.0	1151.7	971.7
30	14.74	212.13	26.75	0.03739	180.1	1151.8	971.7
	15	213.0	26.30	0.03802	181.0	1152.2	971.2
	16	216.3	24.76	0.04038	184.3	1153.4	969.1
	17	219.4	23.40	0.04274	187.5	1154.6	967.1
	18	222.4	22.18	0.04508	190.5	1155.7	965.2
	19	225.2	21.09	0.04742	193.3	1156.7	963.4
	20	228.0	20.10	0.0498	196.0	1157.7	961.7
	21	230.6	19.20	0.0521	198.7	1158.7	960.0
	22	233.1	18.38	0.0544	201.2	1159.6	958.4
	23	235.5	17.64	0.0567	203.6	1160.4	956.8
	24	237.8	16.95	0.0590	206.0	1161.3	955.3
	25	240.1	16.32	0.0613	208.2	1162.1	953.8
	26	242.2	15.73	0.0636	210.4	1162.8	952.4
	27	244.3	15.18	0.0659	212.6	1163.6	951.0
	28	246.4	14.67	0.0681	214.6	1164.3	949.7
	29	248.4	14.20	0.0704	216.6	1165.0	948.4
	30	250.3	13.76	0.0727	218.6	1165.7	947.1
	31	252.2	13.34	0.0749	220.5	1166.3	945.8
	32	254.0	12.95	0.0772	222.4	1166.9	944.6
	33	255.8	12.59	0.0795	224.2	1167.5	943.4
	34	257.6	12.24	0.0818	225.9	1168.1	942.2
	35	259.3	11.91	0.0840	227.7	1168.7	941.0
	36	260.9	11.60	0.0862	229.4	1169.2	939.9

TABLE 2—*Continued*

PROPERTIES OF SATURATED STEAM

Pressure, lb. per sq. in.	Temp., Deg. F.	Volume, cu. ft. per lb.	Weight, per lb. cu. ft.	Heat Content in B.T.U.		Latent heat of vaporization B.T.U.
				of liquid.	of vapor.	
37	262.6	11.31	0.0884	231.0	1169.8	938.8
38	264.2	11.03	0.0907	232.6	1170.3	937.7
39	265.7	10.76	0.0929	234.2	1170.8	936.6
40	267.2	10.51	0.0951	235.8	1171.3	935.5
41	268.7	10.27	0.0974	237.3	1171.8	934.5
42	270.2	10.04	0.0996	238.8	1172.2	933.5
43	271.6	9.82	0.1018	240.2	1172.7	932.5
44	273.0	9.61	0.1040	241.7	1173.2	931.5
45	274.4	9.41	0.1062	243.1	1173.6	930.5
46	275.8	9.22	0.1085	244.5	1174.0	929.6
47	277.1	9.04	0.1107	245.8	1174.4	928.6
48	278.4	8.86	0.1129	247.2	1174.8	927.7
49	279.7	8.69	0.1151	248.5	1175.2	926.8
50	281.0	8.53	0.1173	249.8	1175.6	925.9
51	282.3	8.37	0.1195	251.0	1176.0	925.0
52	283.5	8.22	0.1217	252.3	1176.4	924.1
53	284.7	8.07	0.1239	253.5	1176.7	923.2
54	285.9	7.93	0.1261	254.7	1177.1	922.4
55	287.1	7.80	0.1283	255.9	1177.5	921.5
56	288.2	7.67	0.1304	257.1	1177.8	920.7
57	289.4	7.54	0.1326	258.3	1178.1	919.8
58	290.5	7.42	0.1348	259.5	1178.5	919.0
59	291.6	7.30	0.1370	260.6	1178.8	918.2
60	292.7	7.18	0.1392	261.7	1179.1	917.4
61	293.8	7.07	0.1414	262.8	1179.4	916.6
62	294.9	6.97	0.1435	263.9	1179.7	915.8
63	295.9	6.86	0.1457	265.0	1180.0	915.0
64	296.9	6.76	0.1479	266.1	1180.3	914.3
65	298.0	6.66	0.1501	267.1	1180.6	913.5
66	299.0	6.57	0.1522	268.2	1180.9	912.7
67	300.0	6.48	0.1544	269.2	1181.2	912.0
68	301.0	6.39	0.1566	270.2	1181.5	911.2
69	302.0	6.30	0.1587	271.2	1181.7	910.5
70	302.9	6.22	0.1609	272.2	1182.0	909.8
71	303.9	6.13	0.1630	273.2	1182.3	909.1
72	304.8	6.05	0.1652	274.2	1182.5	908.3
73	305.8	5.97	0.1674	275.1	1182.8	907.6
74	306.7	5.90	0.1695	276.1	1183.0	906.9
75	307.6	5.82	0.1717	277.0	1183.3	906.2
76	308.5	5.75	0.1738	278.0	1183.5	905.5
77	309.4	5.68	0.1760	278.9	1183.8	904.9
78	310.3	5.61	0.1781	279.8	1184.0	904.2
79	311.2	5.55	0.1803	280.7	1184.2	903.5
80	312.0	5.48	0.1824	281.6	1184.4	902.8
81	312.9	5.42	0.1846	282.5	1184.7	902.2
82	313.7	5.35	0.1868	283.4	1184.9	901.5
83	314.6	5.29	0.1889	284.2	1185.1	900.9
84	315.4	5.23	0.1910	285.1	1185.3	900.2
85	316.3	5.18	0.1932	286.0	1185.5	899.6
86	317.1	5.12	0.1953	286.8	1185.7	898.9
87	317.9	5.06	0.1975	287.6	1185.9	898.3
88	318.7	5.01	0.1996	288.5	1186.1	897.7
89	319.5	4.96	0.2017	289.3	1186.3	897.1
90	320.3	4.905	0.2039	290.1	1186.5	896.4
91	321.0	4.854	0.2060	290.9	1186.7	895.8
92	321.8	4.805	0.2081	291.7	1186.9	895.2

TABLE 2—*Continued*

PROPERTIES OF SATURATED STEAM

Pressure, lb. per sq. in.	Temp., Deg. F.	Volume, cu. ft. per lb.	Weight, lb. per cu. ft.	Heat Content in B.T.U.		Latent heat of vaporization. B.T.U.
				of liquid.	of vapor.	
93	322.6	4.756	0.2102	292.5	1187.1	894.6
94	323.3	4.709	0.2124	293.3	1187.3	894.0
95	324.1	4.663	0.2145	294.1	1187.5	893.4
96	324.8	4.617	0.2166	294.8	1187.7	892.8
97	325.6	4.572	0.2187	295.6	1187.8	892.2
98	326.3	4.528	0.2209	296.4	1188.0	891.6
99	327.1	4.484	0.2230	297.2	1188.2	891.0
100	327.8	4.442	0.2251	297.9	1188.4	890.5
101	328.5	4.400	0.2273	298.7	1188.5	889.9
102	329.2	4.359	0.2294	299.4	1188.7	889.3
103	330.0	4.318	0.2316	300.1	1188.9	888.7
104	330.7	4.279	0.2337	300.9	1189.0	888.2
105	331.4	4.240	0.2358	301.6	1189.2	887.6
106	332.0	4.202	0.2380	302.3	1189.4	887.1
107	332.7	4.165	0.2401	303.0	1189.5	886.5
108	333.4	4.128	0.2422	303.7	1189.7	885.9
109	334.1	4.092	0.2444	304.4	1189.8	885.4
110	334.8	4.057	0.2465	305.1	1190.0	884.8
111	335.5	4.022	0.2486	305.8	1190.1	884.3
112	336.1	3.988	0.2508	306.5	1190.3	883.7
113	336.8	3.954	0.2529	307.2	1190.4	883.2
114	337.4	3.921	0.2550	307.9	1190.6	882.7
115	338.1	3.889	0.2572	308.6	1190.7	882.1
116	338.7	3.857	0.2593	309.2	1190.8	881.6
117	339.4	3.826	0.2614	309.9	1191.0	881.1
118	340.0	3.795	0.2635	310.6	1191.1	880.6
119	340.6	3.765	0.2657	311.2	1191.2	880.0
120	341.3	3.735	0.2678	311.9	1191.4	879.5
121	341.9	3.705	0.2699	312.5	1191.5	879.0
122	342.5	3.676	0.2720	313.2	1191.6	878.5
123	343.1	3.648	0.2741	313.8	1191.8	878.0
124	343.7	3.620	0.2762	314.4	1191.9	877.5
125	344.4	3.593	0.2783	315.1	1192.0	876.9
126	345.0	3.566	0.2805	315.7	1192.1	876.4
127	345.6	3.539	0.2826	316.3	1192.3	875.9
128	346.2	3.513	0.2847	316.9	1192.4	875.4
129	346.8	3.487	0.2868	317.6	1192.5	874.9
130	347.4	3.461	0.2889	318.2	1192.6	874.4
131	347.9	3.436	0.2910	318.8	1192.7	873.9
132	348.5	3.412	0.2931	319.4	1192.9	873.5
133	349.1	3.387	0.2952	320.0	1193.0	873.0
134	349.7	3.363	0.2973	320.6	1193.1	872.5
135	350.3	3.340	0.2994	321.2	1193.2	872.0
136	350.8	3.316	0.3016	321.8	1193.3	871.5
137	351.4	3.293	0.3037	322.4	1193.4	871.0
138	352.0	3.270	0.3058	323.0	1193.5	870.5
139	352.5	3.248	0.3079	323.6	1193.6	870.1
140	353.1	3.226	0.3100	324.2	1193.7	869.6
141	353.6	3.204	0.3121	324.7	1193.8	869.1
142	354.2	3.182	0.3142	325.3	1193.9	868.6
143	354.8	3.161	0.3163	325.9	1194.0	868.2
144	355.3	3.140	0.3184	326.5	1194.1	867.7
145	355.8	3.120	0.3206	327.0	1194.2	867.2
146	356.3	3.099	0.3227	327.6	1194.3	866.8
147	356.9	3.079	0.3248	328.2	1194.4	866.3
148	357.4	3.059	0.3269	328.7	1194.5	865.8

TABLE 2—*Continued*

PROPERTIES OF SATURATED STEAM

Pressure, lb. per sq. in.	Temp., Deg. F.	Volume, cu. ft. per lb.	Weight, lb. per cu. ft.	Heat Content in B.T.U.		Latent heat of vaporization, B.T.U.
				of liquid.	of vapor.	
149	357.9	3.039	0.3290	329.3	1194.6	865.4
150	358.5	3.020	0.3311	329.8	1194.7	864.9
152	359.5	2.982	0.3353	330.9	1194.9	864.0
154	360.5	2.945	0.3396	332.0	1195.1	863.1
156	361.6	2.909	0.3438	333.1	1195.3	862.3
158	362.6	2.874	0.3480	334.1	1195.5	861.4
160	363.6	2.839	0.3522	335.2	1195.7	860.5
162	364.6	2.806	0.3564	336.2	1195.8	859.6
164	365.6	2.773	0.3606	337.3	1196.0	858.7
166	366.5	2.741	0.3648	338.3	1196.2	857.9
168	367.5	2.710	0.3691	339.3	1196.3	857.0
170	368.5	2.679	0.3733	340.3	1196.5	856.2
172	369.4	2.649	0.3775	341.3	1196.6	855.3
174	370.4	2.620	0.3817	342.3	1196.8	854.5
176	371.3	2.591	0.3859	343.3	1196.9	853.6
178	372.2	2.563	0.3901	344.3	1197.1	852.8
180	373.1	2.536	0.3943	345.2	1197.2	852.0
182	374.0	2.509	0.3985	346.2	1197.4	851.2
184	374.9	2.483	0.4027	347.1	1197.5	850.4
186	375.8	2.457	0.4069	348.1	1197.6	849.5
188	376.7	2.432	0.4111	349.0	1197.8	848.7
190	377.6	2.408	0.4154	350.0	1197.9	847.9
192	378.5	2.383	0.4196	350.9	1198.0	847.1
194	379.3	2.360	0.4238	351.8	1198.1	846.3
196	380.2	2.337	0.4280	352.7	1198.2	845.6
198	381.0	2.314	0.4322	353.6	1198.4	844.8
200	381.9	2.292	0.4364	354.5	1198.5	844.0
205	383.9	2.238	0.4469	356.7	1198.7	842.1
210	386.0	2.186	0.457	358.8	1199.0	840.2
215	388.0	2.137	0.468	361.0	1199.2	838.3
220	390.0	2.090	0.478	363.0	1199.5	836.5
225	391.9	2.045	0.489	365.1	1199.7	834.6
230	393.8	2.002	0.499	367.1	1199.9	832.8
235	395.6	1.961	0.510	369.1	1200.1	831.0
240	397.5	1.921	0.521	371.0	1200.3	829.3
245	399.3	1.883	0.531	373.0	1200.5	827.5
250	401.1	1.846	0.542	374.9	1200.6	825.8
255	402.9	1.811	0.552	376.7	1200.8	824.1
260	404.5	1.777	0.563	378.6	1201.0	822.4
265	406.2	1.745	0.573	380.4	1201.1	820.7
270	407.9	1.713	0.584	382.2	1201.2	819.1
275	409.6	1.683	0.594	383.9	1201.4	817.4
280	411.2	1.654	0.605	385.7	1201.5	815.8
285	412.8	1.625	0.615	387.4	1201.6	814.2
290	414.4	1.598	0.626	389.1	1201.7	812.6
295	415.9	1.571	0.636	390.8	1201.8	811.0
300	417.5	1.545	0.647	392.4	1201.9	809.4
325	424.9	1.428	0.700	400.4	1202.2	801.8
350	431.9	1.327	0.753	408.0	1202.5	794.5
375	438.5	1.239	0.807	415.1	1202.6	787.5
400	444.8	1.162	0.860	422.0	1202.5	780.6
450	456.5	1.033	0.968	434.8	1202.2	767.4
500	467.2	0.928	1.077	446.6	1201.7	755.0
600	486.5	0.770	1.30	468.0	1199.8	731.8
700	503.4	.656	1.52	487.1	1197.4	710.3
800	518.5	.570	1.76	504.3	1194.4	690.1

TABLE 3

WEIGHT AND SPECIFIC HEAT OF WATER

(From Goodenough's "Properties of Steam and Ammonia")

Temp., Deg. F.	Volume, Cu.ft. per Lb.	Weight, Lb. per Cu.ft.	Specific Heat.	Temp., Deg. F.	Volume, Cu.ft. per Lb.	Weight, Lb. per Cu.ft.	Specific Heat.
20	0.01603	62.37	1.0210	370	0.01829	54.66	1.053
30	0.01602	62.42	1.0104	380	0.01843	54.25	1.057
40	0.01602	62.43	1.0048	390	0.01857	53.84	1.062
50	0.01602	62.42	1.0015	400	0.0187	53.42	1.067
60	0.01603	62.37	0.9995	410	0.0189	52.99	1.072
70	0.01605	62.30	0.9982	420	0.0190	52.55	1.078
80	0.01607	62.22	0.9975	430	0.0192	52.11	1.083
90	0.01610	62.11	0.9971	440	0.0194	51.66	1.089
100	0.01613	62.00	0.9970	450	0.0195	51.2	1.095
110	0.01616	61.86	0.9971	460	0.0197	50.7	1.101
120	0.01620	61.71	0.9974	470	0.0199	50.2	1.107
130	0.01625	61.55	0.9978	480	0.0201	49.7	1.114
140	0.01629	61.38	0.9984	490	0.0203	49.2	1.121
150	0.01634	61.20	0.9990	500	0.0205	48.7	1.130
160	0.01639	61.00	0.9998	510	0.0208	48.2	1.140
170	0.01645	60.80	1.0007	520	0.0210	47.6	1.151
180	0.01651	60.58	1.0017	530	0.0212	47.1	1.164
190	0.01657	60.36	1.0028	540	0.0215	46.5	1.181
200	0.01663	60.12	1.0039	550	0.0218	45.9	1.200
210	0.01670	59.88	1.0052	560	0.0221	45.2	1.222
220	0.01677	59.63	1.0068	570	0.0224	44.6	1.249
230	0.01684	59.37	1.0085	580	0.0227	44.0	1.281
240	0.01692	59.11	1.0104	590	0.0231	43.3	1.318
250	0.01700	58.83	1.0125	600	0.0235	42.6	1.362
260	0.01708	58.55	1.0148	610	0.024	41.8	1.415
270	0.01716	58.26	1.0173	620	0.024	41.0	1.479
280	0.01725	57.96	1.020	630	0.025	40.2	1.559
290	0.01735	57.65	1.023	640	0.025	39.2	1.661
300	0.01745	57.32	1.026	650	0.026	38.2	1.793
310	0.01755	56.98	1.029	660	0.027	37.2	
320	0.01766	56.62	1.033	670	0.028	36.0	
330	0.01778	56.24	1.036	680	0.029	34.5	
340	0.01790	55.85	1.040	690	0.031	32.6	
350	0.01803	55.46	1.044	700	0.034	29.7	
360	0.01816	55.06	1.048	706.3	0.048	20.9	

TABLE 4

SPECIFIC HEATS OF LIQUIDS

(From Roentgen's Thermodynamics)

Water	1.0000	Mercury	0.0333
Lead (melted)	0.0402	Alcohol (absolute)	0.7000
Sulphur (melted)	0.2340	Fusel oil	0.5640
Bismuth (melted)	0.0308	Benzine	0.4500
Tin (melted)	0.0637	Ether	0.5034
Sulphuric acid	0.3350		

TABLE 5

SPECIFIC HEATS OF GASES

(From Roentgen's Thermodynamics)

	Constant Pressure.	Constant Volume.
Air	0.23751	0.16847
Oxygen	0.21751	0.15507
Hydrogen	3.40900	2.41226
Nitrogen	0.24380	0.17273
Superheated steam *	0.4805	0.346
Carbonic acid	0.217	0.171
Olefiant gas C_2H_4 (ethylene)	0.404	0.332
Carbonic oxide	0.2479	0.1758
Ammonia	0.508	0.299
Ether	0.4797	0.3411
Alcohol	0.4534	0.399
Acetic acid	0.4125	
Chloroform	0.1567	

In addition to the above, the following are given by other authorities. (Selected from various sources.)

TABLE 6

SPECIFIC HEATS OF METALS

Platinum, 32° to 446° F.	0.0333	Wrought iron (Petit and Dulong)	
(Increased 0.000305 for each 100° F.)		32° to 212°	0.1098
Cadmium	0.0567	32° to 392°	0.115
Brass	0.0939	32° to 572°	0.1218
Copper, 32° to 212° F.	0.094	32° to 662°	0.1255
" 32° to 572° F.	0.1013	Iron at high temperatures.	
Zinc, 32° to 212° F.	0.0927	(Pionchon, *Comptes Rendus*, 1887)	
" 32° to 572° F.	0.1015	1382° to 1832° F.	0.213
Nickel	0.1086	1749° to 1843° F.	0.218
Aluminum, 0° F. to melting-point (A. E. Hunt)	0.2185	1922° to 2192 F.	0.199

Dr.-Ing. P. Oberhoffer, in *Zeit. des Vereines Deutscher Ingenieure* (*Eng. Digest*, Sept., 1908), describes some experiments on the specific heat of nearly pure iron. The following mean specific heats were obtained.

Temp. F.	500	600	800	1000	1200	1300
Sp. Ht.	0.1228	0.1266	0.1324	0.1388	0.1462	0.1601
Temp F.	1500	1800	2100	2400	2700	
Sp. Ht.	0.1698	0.1682	0.1667	0.1662	0.1666	

The specific heat increases steadily between 500 and 1200 F. Then it increases rapidly to 1400, after which it remains nearly constant.

TABLE 7

SPECIFIC HEATS OF OTHER SOLIDS

Brickwork and masonry, about	0.20	Coal	0.20 to 0.241
Marble	0.210	Coke	0.203
Chalk	0.215	Graphite	0.202
Quicklime	0.217	Sulphate of lime	0.197
Magnesian limestone	0.217	Magnesia	0.222
Silica	0.191	Soda	0.231
Corundum	0.198	Quartz	0.188
Stones generally	0.2 to 0.22	River sand	0.195

TABLE 8

SPECIFIC HEATS OF WOODS

Oven dried, 20 varieties, specific heat nearly the same for all, average 0.327. (U. S. Forest Service, 1911.)

TABLE 9

SPECIFIC HEATS OF LIQUIDS

Alcohol, density 0.793	0.622	Olive oil	0.310
Sulphuric acid, density 1.87	0.335	Benzine	0.393
" " " 1.30	0.661	Turpentine, density 0.872	0.472
Hydrochloric acid	0.600	Bromine	1.111

TABLE 10

SPECIFIC HEATS OF GASES

	At Constant Pressure.	At Constant Volume.
Sulphurous acid	0.1553	0.1246
Light carbureted hydrogen, marsh gas (CH_4)	0.5929	0.4683
Blast-furnace gases	0.2277	.....

TABLE 11

TABLE OF SPECIFIC HEAT OF GASEOUS PRODUCTS OF COMBUSTION REFERRED TO THE PROPORTION OF CARBON DIOXIDE

Proportion of Carbon Dioxide	Specific Heat.	Proportion of Carbon Dioxide	Specific Heat.
5 per cent	0.312	11 per cent	0.319
6 "	0.314	12 "	0.320
7 "	0.315	13 "	0.321
8 "	0.316	14 "	0.322
9 "	0.317	15 "	0.323
10 "	0.318		

TABLE 12

HEAT OF COMBUSTION OF SUBSTANCES

	Calories.	B.T.U.	
Crystallized carbon to CO_2	7,859	14,146	Berthelot
" " to CO	2,405	4,329	"
Amorphous carbon to CO_2	8,137	14,647	"
" " to CO	2,489	4,480	"
Graphite to CO_2	7,901	14,222	"
Petroleum coke to CO_2	8,017	14,503	Mahler
Gas coke to CO_2	8,047	14,485	Favre and Silbermann
Carbon vapor to CO_2	11,328	20,390	Calculated
Coal (pure and dry)	7800–9000	14,040–16,200	Various
Lignite (pure and dry)	6000–7000	10,800–12,600	"
Beech charcoal	7,140	12,852	Schwackhöfer
Soft charcoal	7,071	12,723	"
Cellulose	4,200	7,560	Berthelot
Soft resinous wood	5,050	9,090	Gottlieb
Hard wood	4,750	8,550	"
Peat	5,940	10,692	Bainbridge
Cane sugar	3,961	7,130	Berthelot
Asphalt	9,532	17,159	Slosson and Colburn
Pitch	8,400	15,120	Anonymous
Naphthalin	9,690	16,842	Berthelot
Paraffin	11,000	19,800	Mahler
Tallow	9,500	17,100	Stohmann
Sulphur	2,500	4,500	Berthelot
Petroleum	9600–11,000	17,280–19,800	Various
Schist-oil	9000–10,000	16,200–18,000	"
Heavy coal gas oil	8,900	16,020	Ste. Claire Deville
Cotton oil	9,500	17,100	Anonymous
Rape oil	9,489	17,080	Stohmann
Olive oil	9,473	17,051	"
Sperm oil	10,000	18,000	Gibson
Hydrogen	34,500	62,100	Berthelot
Carbon monoxide	2,435	4,383	"
Marsh gas	13,343	24,017	"
Olefiant gas	12,182	21,898	"
Acetylene	12,142	21,856	"
Carbon vapor (diamond)	11,134	20,041	"
Coal gas	4440–7370	7990–12,266	Various
Petroleum gas	10,800	19,440	Anonymous
Air producer gas	773–1370	1391–2466	Various
Water gas	2350–3032	4230–5458	"
Mixed gas	1015–1548	1827–2786	"

The heating value of methane, CH_4, if calculated according to its composition by the formula 8080C+34,462H, using Favre and Silbermann's figures, is 14,675 Centigrade heat-units, instead of 13,063, the value determined by a calorimeter, a difference of 1612 heat-units. The calculated heating value of ethylene, C_2H_4, is 11,849, and that of benzole gas, C_4H_4, is 10,109 heat-units, differing respectively from the calorimetric values only 9 and 7 heat-units.

TABLE 13

SPECIFIC GRAVITY AND WEIGHT OF GASES AT ATMOSPHERIC PRESSURE AND 32 DEG. FAHR

	Density, Air = 1.	Density, H = 1.	Grams per Liter.	Pounds per Cubic Foot.	Cubic Feet per Pound.
Air	1.0000	14.444	1.2931	0.080728	12.388
Oxygen, O	1.1052	15.963	1.4291	0.08921	11.209
Hydrogen, H	0.0692	1.000	0.0895	0.00559	178.931
Nitrogen, N	0.9701	14.012	1.2544	0.07831	12.770
Carbon monoxide, CO	0.9671	13.968	1.2505	0.07807	12.810
Carbon dioxide, CO_2	1.5197	21.950	1.9650	0.12267	8.152
Methane, marsh-gas, CH_4	0.5530	7.987	0.7150	0.04464	22.429
Ethylene, C_2H_4	0.9674	13.973	1.2510	0.07809	12.805
Acetylene, C_2H_2	0.8982	12.973	1.1614	0.07251	13.792.
Ammonia, NH_3	0.5889	8.506	0.7615	0.04754	21.036
Water vapor, H_2O	0.6218	8.981	0.8041	0.05020	19.922
Sulphur dioxide, SO_2	2.213	31.965	2.862	0.1787	5.597

TABLE 14

OXYGEN AND AIR REQUIRED FOR THE COMBUSTION OF CARBON, HYDROGEN, ETC.

	Chemical Reaction.	Pounds O per Pound Fuel.	Pounds N = 3.22 × O	Air per Pound = 4.32 × O.	Gaseous Product per Pound.
Carbon to CO_2	$C+2O=CO_2$	2 2/3	8.85	11.52	12.52
Carbon to CO	$C+O=CO$	1 1/3	4.43	5.76	6.76
Carbon monoxide to CO_2	$CO+O=CO_2$	4/7	1.90	2.47	3.47
Hydrogen to H_2O	$2H+O=H_2O$	8	26.56	34.56	35.56
Methane, CH_4 to CO_2 and H_2O	$CH_4+4O=CO_2+2H_2O$	4	13.28	17.28	18.28
Sulphur to SO_2	$S+2O=SO_2$	1	3.32	4.32	5.32

TABLE 15

VOLUME OF OXYGEN TO FORM WATER WITH THE HYDROGEN OF COAL

Per Cent of Hydrogen.	Liters of Oxygen per Kg. of Coal.	Cubic Feet of Oxygen per Lb. of Coal.	Per Cent of Hydrogen.	Liters of Oxygen per Kg. Coal.	Cubic Feet of Oxygen per Lb. of Coal.
1	55.9	0.896	6	335	5.397
2	112	1.792	7	391	6.283
3	168	2.699	8	446	7.170
4	223	3.585	9	502	8.096
5	279	4.481			

TABLE 16

IGNITION POINT OF GASES (Mayer and Münch) [1]

Marsh gas, CH_4	667° C.	1233° F.
Ethane, C_2H_6	616	1141
Propane, C_3H_8	547	1017
Acetylene, C_2H_2	580	1076
Propylene, C_3H_6	504	939

[1] Berichte der deutschen Chemische Gesellschaft, xxvi, 2421.

TABLE 17

RELATION BY WEIGHT AND VOLUME OF THE COMPONENTS OF AIR

Air contains by volume:

Nitrogen	78.35
Oxygen	20.77
Aqueous vapor	0.84
Carbon dioxide	0.04
	100.00

Deducting the carbonic acid and aqueous vapor, we have:

Nitrogen	By volume:	79.04	By weight:	76.83
Oxygen	" "	20.96	" "	23.17
		100.00		100.00

Ratio of nitrogen to oxygen:

By volume, $\frac{N}{O}=3.771$. By weight, $\frac{N}{O}=3.32$.

Ratio of air to oxygen:

By volume, $\frac{Air}{O}=4.771$ By weight, $\frac{Air}{O}=4.315$.

Ratio of air to nitrogen:

By volume, $\frac{Air}{N}=1.265$. By weight, $\frac{Air}{N}=1.302$.

Conversion of Temperatures. A handy rule for transforming Centigrade to Fahrenheit degrees is: *Double the Centigrade degrees, subtract* 10 *per cent and add* 32.

Example: Find the Fahrenheit temperature corresponding to 320 deg. Cent.

$$(2\times320)-64+32=608.$$

To transform Fahrenheit degrees to Centigrade: *Subtract* 32 *and divide by* 1.80.

Example: Find the Centigrade temperature corresponding to 500 deg. Cent.

$$(500-32)\div1.80=260.$$

TABLE 18

TEMPERATURE CONVERSION TABLE

(By Dr. Leonard Waldo)

Reprint from *Metallurgical and Chemical Engineering*

C°.	0	10	20	30	40	50	60	70	80	90
	F	F	F	F	F	F	F	F	F	F
−200	−328	−346	−364	−382	−400	−418	−436	−454		
−100	−148	−166	−184	−202	−220	−238	−256	−274	−292	−310
−0	+32	+14	−4	−22	−40	−58	−76	−94	−112	−130
0	32	50	68	86	104	122	140	158	176	194
100	212	230	248	266	284	302	320	338	356	374
200	392	410	428	446	464	482	500	518	536	554
300	572	590	608	626	644	662	680	698	716	734
400	752	770	788	806	824	842	860	878	896	914
500	932	950	968	986	1004	1022	1040	1058	1076	1094
600	1112	1130	1148	1166	1184	1202	1220	1238	1256	1274
700	1292	1310	1328	1346	1364	1382	1400	1418	1436	1454
800	1472	1490	1508	1526	1544	1562	1580	1598	1616	1634
900	1652	1670	1688	1706	1724	1742	1760	1778	1796	1814
1000	1832	1850	1868	1886	1904	1922	1940	1958	1976	1994
1100	2012	2030	2048	2066	2084	2102	2120	2138	2156	2174
1200	2192	2210	2228	2246	2264	2282	2300	2318	2336	2354
1300	2372	2390	2408	2426	2444	2462	2480	2498	2516	2534
1400	2552	2570	2588	2606	2624	2642	2660	2678	2696	2714
1500	2732	2750	2768	2786	2804	2822	2840	2858	2876	2894
1600	2912	2930	2948	2966	2984	3002	3020	3038	3056	3074
1700	3092	3110	3128	3146	3164	3182	3200	3218	3236	3254
1800	3272	3290	3308	3326	3344	3362	3380	3398	3416	3434
1900	3452	3470	3488	3506	3524	3542	3560	3578	3596	3614
2000	3632	3650	3668	3686	3704	3722	3740	3758	3776	3794
2100	3812	3830	3848	3866	3884	3902	3920	3938	3956	3974
2200	3992	4010	4028	4046	4064	4082	4100	4118	4136	4154
2300	4172	4190	4208	4226	4244	4262	4280	4298	4316	4334
2400	4352	4370	4388	4406	4424	4442	4460	4478	4496	4514
2500	4532	4550	4568	4586	4604	4622	4640	4658	4676	4694
2600	4712	4730	4748	4766	4784	4802	4820	4838	4856	4874
2700	4892	4910	4928	4946	4964	4982	5000	5018	5036	5054
2800	5072	5090	5108	5126	5144	5162	5180	5198	5216	5234
2900	5252	5270	5288	5306	5324	5342	5360	5378	5396	5414
3000	5432	5450	5468	5486	5504	5522	5540	5558	5576	5594
3100	5612	5630	5648	5666	5684	5702	5720	5738	5756	5774
3200	5792	5810	5828	5846	5864	5882	5900	5918	5936	5954
3300	5972	5990	6008	6026	6044	6062	6080	6098	6116	6134
3400	6152	6170	6188	6206	6224	6242	6260	6278	6296	6314
3500	6332	6350	6368	6386	6404	6422	6440	6458	6476	6494
3600	6512	6530	6548	6566	6584	6602	6620	6638	6656	6674
3700	6692	6710	6728	6746	6764	6782	6800	6818	6836	6854
3800	6872	6890	6908	6926	6944	6962	6980	6998	7016	7034
3900	7052	7070	7088	7106	7124	7142	7160	7178	7196	7214
C°.	0	10	20	30	40	50	60	70	80	90

C°.	F°.
1	1.8
2	3.6
3	5.4
4	7.2
5	9.0
6	10.8
7	12.6
8	14.4
9	16.2
10	18.0

F°.	C°.
1	.56
2	1.11
3	1.67
4	2.22
5	2.78
6	3.33
7	3.89
8	4.44
9	5.00
10	5.56
11	6.11
12	6.67
13	7.22
14	7.78
15	8.33
16	8.89
17	9.44
18	10.00

EXAMPLES: 1347° C. = 2444° F. + 12°.6 F. = 2456°.6 F.: 3367° F. = 1850° C. + 2°.78 C. = 1852°.78 C.

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